Doc. #	**TTCS-SYSU-MECH-AN-004-3.0**		
Project	**AMS-TTCS**		
Title	**ACCUMULATOR STRUCTURE ANALYSIS**		
Create Date	2007-4-29 21:05	**Save date**	2008-12-17 15:51
File name	TTCS-SYSU-MECH-AN-004-3.0-Accum&Brackes&Thermastat__Structure_Analysis_via_IDEAS12.doc	**Issue**	3.0
Distribution	Internal/	**Pages**	160

	Name	Signature	Date	Department/Organization
Prepared by	Y.Y.Zhang Y.Chen Y.C.Zhang			SYSU
Checked by	Xinmei Qi			SYSU
Approved by	Z.H.He			SYSU

Distribution List			
Internal		**External**	
Name	**Department**	**Name**	**Organization**

Z.H.He	SYSU	Es.Van.J	NLR
S.S.Zheng	SYSU	Corrado	INFN
SS LV	SYSU	Elisa Laudi	INFN
TX II	SYSU	Antonio Alvino	INFN
C.H.Feng	SYSU	Lauritzen, Carl A	Nasa
		Chittur Balan	Nasa

CHANGE RECORD			
ISSUE	*DATE*	*AUTHOR*	*REASON FOR CHANGE AND AFFECTED SECTIONS*
1.0	*Feb.2007*	*G.Y.Chen*	*Model change*
2.0	*March.2008*	*YY.Zhang*	*Design modification, design frozen*
3.0	*Dec. 2008*	*Y.C.Zhang*	*Boit list modification and frozen;* *Bolt list file [RD11], Bolt MoS changed*

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

1. SCOPE

The document provides the following contents about Accumulator's assembly.

- Static Structural Analysis for launching/landing load cases
- Bolt connection analysis for launching/landing load cases
- Fail-Safe analysis for launching/landing load cases
- Thermal analysis for the critical cases in orbit
- Static Structural Analysis for in orbit load cases
- Bolt connection analysis for in orbit load cases
- Fail-Safe analysis for in orbit load cases
- Modal analysis

2. DOCUMENTS

The documents listed here contain the additional information relevant to the text.

2.1 References

Table 2-1 Reference Documents

Number	Document	Author
RD1	BOX_S_May_2004.doc	10 May. 2004 by C.Gargiulo, R.Becker
RD2	C_boxFEM AnalysisJun10.ppt	11 Jun. 2004 by Wang Yi, Robert Becker
RD3	TTCB_USS_Analysis_SYSU_I-deasV11_result_July2006.doc	20 July 2006 by X. H. Diao, X. M. Qi. etc
RD4	TTCS-SYSU-AN-Mechanical-Accu&Thermal-001-20061022.pdf	22 Oct 2006 by G.Y.Chen,etc

RD5	Accumulator verification load cases summary_rev3.doc	12 Nov 2006 by J. van Es,etc
RD6	TTCS-SYSU-MECH-AN-003-1[1].0 Stress_An_SolderingArea_ACCU_PeltierSaddle.doc	19 Jan 2007 by G.Y.Chen.etc
RD7	TTCS-SYSU-MECH-AN-002-1[1].0 Accum&Brackets&thermastats_Structure_Analysis_via_IDEAS11	01-Feb 2007 by G.Y. Chen,etc.
RD8	TTCS-SYSU-MECH-AN-002-1[1].0 Accu-Supplement.doc	11-Feb 2007 by G.Y.Chen, X.M. Qi, etc
RD9	TTCS-SYSU-MECH-AN-004-1[1].0 Accu_ThermalStress_Analysis_via_IDEAS11	01-Feb 2007 by G.Y. Chen,Y.Chen,etc.
RD10	TTCS-SYSU-AN-001-2.0_TTCS-Accumulator Thermal Safety Analysis.pdf	10 Sep 2006 by Y.Chen, Z.H,He, etc
RD11	TTCB_Bolted_joint_20081104-8SYSU.xls	Elisa, Dec.,2008

2.2 Abbreviations and Acronyms

Table 2-2 Abbreviations and Acronyms

Abbreviations	Description
Accu	Accumulator
AHP	Accumulator Heat Pipe
EOL	End of Life
HP	Heat pipe
HX	Heat Exchanger
MDP	Maximum Design Pressure
MDT	Maximum Design Temperature

TS	Thermostat
TM	Telemonitoring
TTCE	Tracker Thermal Control Electronics
TTCS	Tracker Thermal Control System
TTCS-SS	TTCS-Space Segment
SST	Stainless steel
Margins of Safety	MoS
DOF	Degree of Freedom
FS	Factor of Safety

3. INTRODUCTION

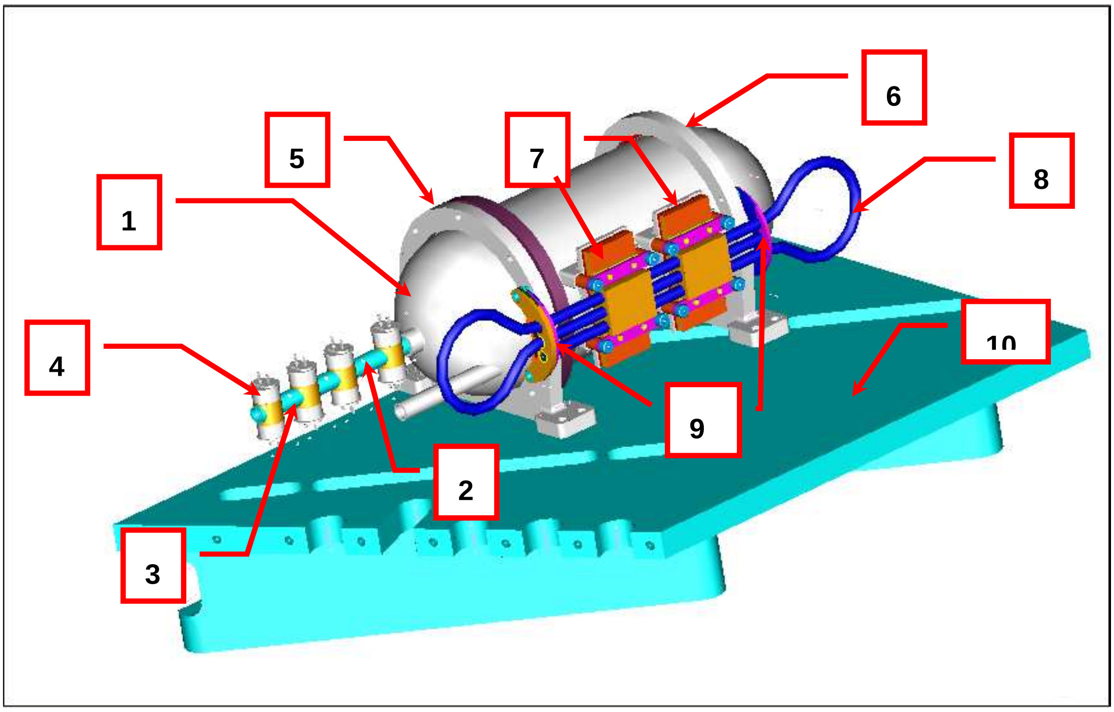
The accumulator is the control room of the TTCS-loop. Its functions are:

- To regulate the evaporator temperature in tracker.
- To account for the expansion of the working fluid.
- To account for the liquid front changes in the condenser during operation.

The main components of accumulator assembly are:

- Accumulator
- Accumulator Heat Pipe
- Accumulator Heater
- Thermostats and Their Mounting Saddles
- Clamp assembly
- Slide assembly
- Peltier elements and Their Mounting Saddles
- Peltier Pipes
- Peltier Pipe Fix

Figure 3-1 Shows the Assembly of Accumulator Components



1 Accumulator **2** Accumulator Heat Pipe **3** Accumulator Heater **4** Thermostats and Their Mounting Saddles **5** Clamp assembly **6** Slide assembly **7** Peltier elements and Their Mounting Saddles **8** Peltier Pipes **9** Peltier Pipe Fix **10** Base Plate

Figure 3-1 Accumulator Assembly

The Base Plate is added to the assembly to simulate the bolt connection between the Accumulator and TTCB.

The Materials of each components are listed in table 4-2.

4. FINITE ELEMENT MODELING

4.1 Finite Element Model

FEM of Different Components are created separately.

Table 4-1 lists the Material Properties for each Material used in the model. Table 4-2 shows the Material and Element type used in Accumulator Assembly. Table 4-3 shows the Element Mass for each component's FEM.

Table 4-1 Materials Properties Data

Material	Density (g/mm3)	Elastic modulus E (N/mm2)	Poisson's ratio	Yield Stress (N/mm2)	Ultimate Stress (N/mm2)	CTE X10-6/oC
Copper	0.00896	119000	0.3	80	220	17
316Ln	0.0079	199375	0.27	335	650	15
Al 7075	0.0028	71019	0.33	393	468.8	23.6
316L	0.00796	196000	0.27	240	550	18
Accumulator Heater	0.00796	1960*	0.27	240	550	18
Sn60Pb	0.00934	33580	0.4	30.2	60	24

*Note: The Accumulator Heater is wired on Heat Pipe and wire material is 316L. Because it is not loaded and only mass distribution is took into account, the density in simulation takes the value of 316L, but Elastic modules is decreased by 2 order.

Table 4-2 Material of Accumulator Assembly

Component		Material	Element type	Max Element Length(mm)
Accumulator Assembly	**Accumulator**	316Ln	3D Solid	2
	Soldering layer	Sn60Pb	3D Solid	2 Calculation Thickness:0.4mm
	Peltier Copper Saddle	Copper	3D Solid	2

<table>
<tr><td rowspan="4">Accumulator Heater Assembly</td><td colspan="2">Accumulator Heat Pipe</td><td>316L</td><td>3D Solid</td><td>2</td></tr>
<tr><td colspan="2">Accumulator Heater</td><td>Accumulator Heater*</td><td>3D Solid</td><td>2</td></tr>
<tr><td colspan="2">Thermostats Saddle</td><td>Copper</td><td>3D Solid</td><td>4</td></tr>
<tr><td colspan="2">Thermostates</td><td>---</td><td>3DSolid</td><td>4</td></tr>
<tr><td rowspan="2">TS Saddle</td><td colspan="2">Saddle Base</td><td>Copper</td><td>3D Solid</td><td>2</td></tr>
<tr><td colspan="2">THERMASTAT</td><td>---</td><td>3DSolid</td><td>4</td></tr>
<tr><td colspan="2" rowspan="3">Fixed Bracket Clamp assembly</td><td>Clamp</td><td>Al 7075</td><td>3D Solid</td><td>4</td></tr>
<tr><td>Clamp Collar</td><td>316L</td><td rowspan="2">3D Solid</td><td rowspan="2">4</td></tr>
<tr><td>Clamp Wedge</td><td>Al 7075</td></tr>
<tr><td colspan="2" rowspan="2">Slide Bracket assembly</td><td>Slide</td><td>Al 7075</td><td rowspan="2">3D Solid</td><td rowspan="2">4</td></tr>
<tr><td>Slide Ring</td><td>------</td></tr>
<tr><td colspan="3">Peltier HX(PELTIER Heat Exchanger)</td><td>Copper</td><td>3D Solid</td><td>2</td></tr>
<tr><td colspan="3">Peltier Pipe</td><td>316L</td><td>Beam</td><td>4</td></tr>
<tr><td colspan="3">Peltier Pipe Fixer</td><td>316L</td><td>3D Solid</td><td>4</td></tr>
<tr><td colspan="3">Spring Press (Peltier Heat Exchanger press)</td><td>316L</td><td>3D Solid</td><td>4</td></tr>
<tr><td colspan="3">Spring Support</td><td>Al 7075</td><td>3D Solid</td><td>4</td></tr>
<tr><td colspan="3">Base Plate</td><td>Al 7075</td><td>3D Solid</td><td>15</td></tr>
</table>

*Note：Accumulator heater is wire winding on Heat Pipe and is dealt with differently in simulation.

——— : part is treated as mass equivalent in the simulation.

Table 4-3 Allotted Element Mass of Accumulator Assembly

Component	**Element Mass** (kg)	**Number**	**Total Mass**(kg)	**Remark**
Accumulator	2.5	1	2.500	1.5kg Mass added for the Mass of fluid
Accumulator Heat Pipe Assembly	0.230	1	0.230	0.02kg Mass added for the Mass of fluid
THERMASTAT	0.0215	2	0.043	
Fixed Bracket Clamp	0.133	1	0.133	
Fixed Bracket Clamp COLLAR & Ring	0.242	1	0.242	
Slide Bracket Clamp assembly	0.137	1	0.137	
Peltier	0.100	4	0.400	
Peltier HE Presser	0.004	4	0.016	
Peliter Heater Support	0.002	4	0.008	
Peltier Copper Saddle	0.122	2	0.244	
Peltier Heat Exchanger	0.107	2	0.214	
Peltier Pipe	0.099	1	0.099	
Peltier Pipe Fix	0.008	2	0.016	
Totals:			Assembly Mass	Additive Mass
			4.282	1.520kg
Total Mass in the Model (Components' Mass + Additive Mass):				**5.802kg**

4.1.1 FEM Mesh for the Components

Accumulator Assembly (Figure 4-1~Figure4-4)

Accumulator:

The Model is fully meshed with tetrahedron & hexahedral 3D Solid elements.

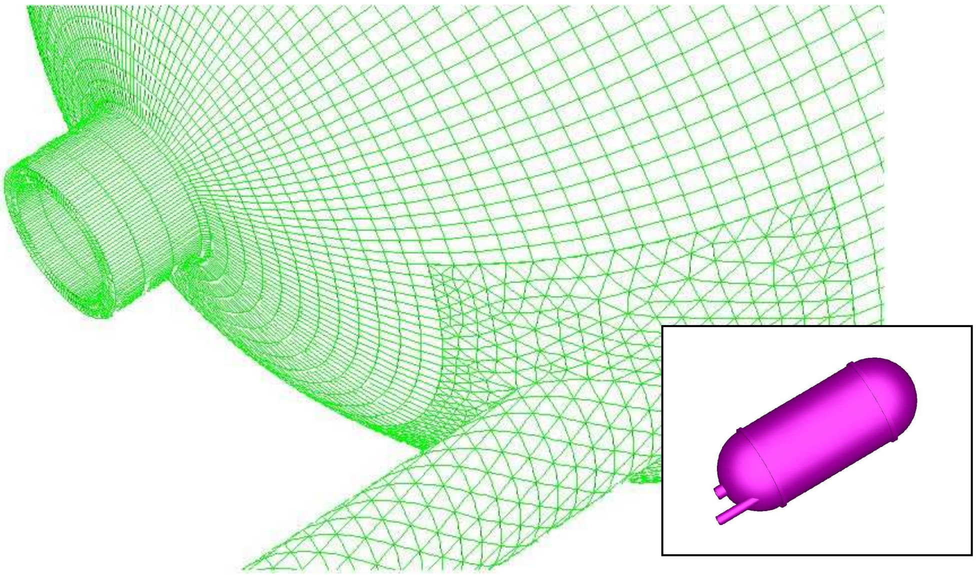


Figure 4-1 Accumulator FEM

Soldering layer(Figure 4-2)

The Model is fully meshed with hexahedral 3D Solid elements.

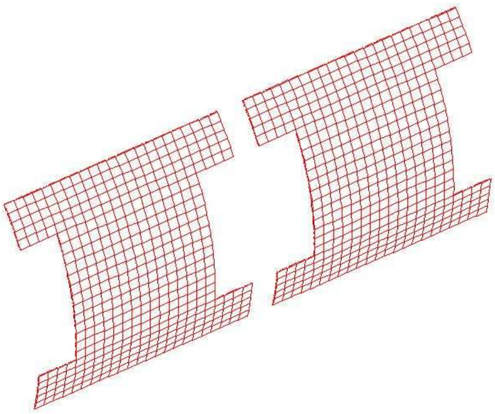


Figure 4-2 Soldering layer between Accumulator & Peltier Copper Saddle FEM

Peltier Copper Saddle (Figure 4-3~ Figure 4-4)

The Model is fully meshed with hexahedral 3D Solid elements.

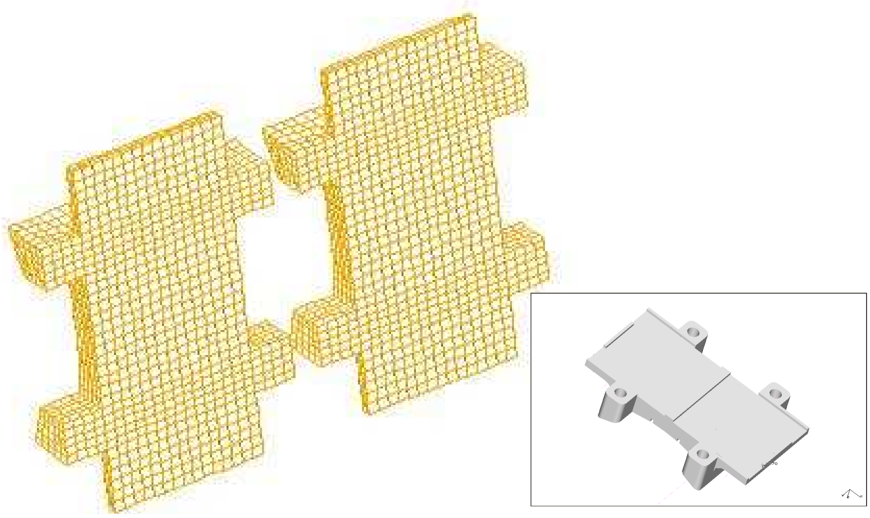
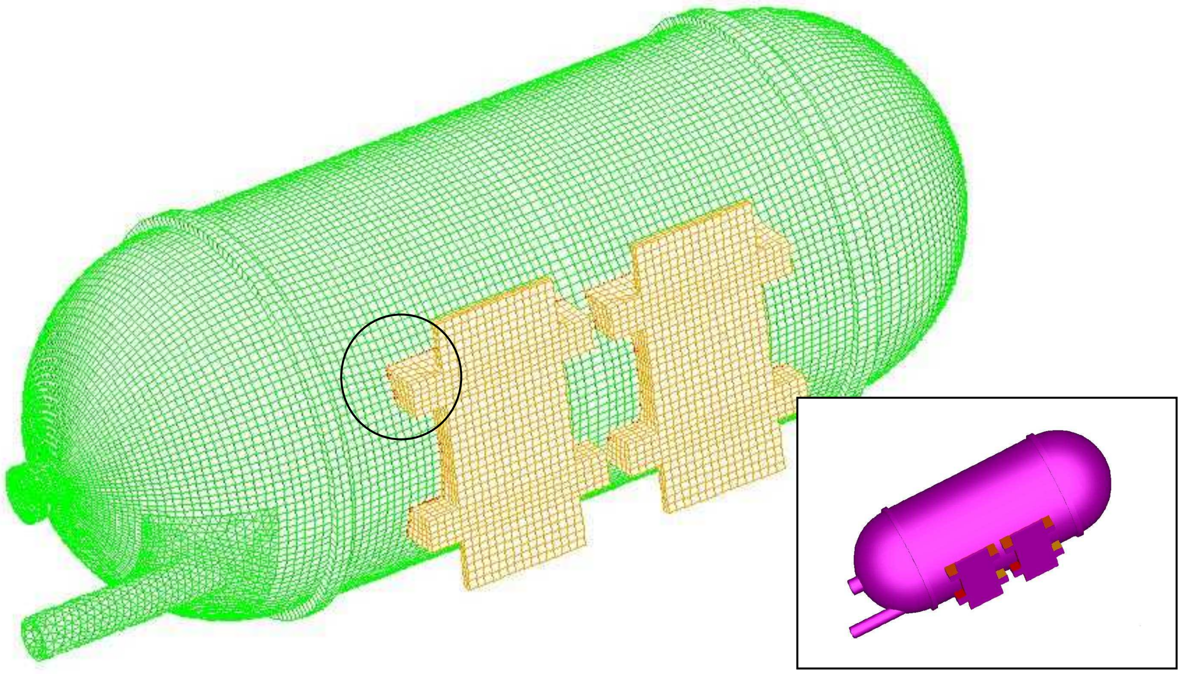


Figure 4-3 Peltier Copper Saddle FEM



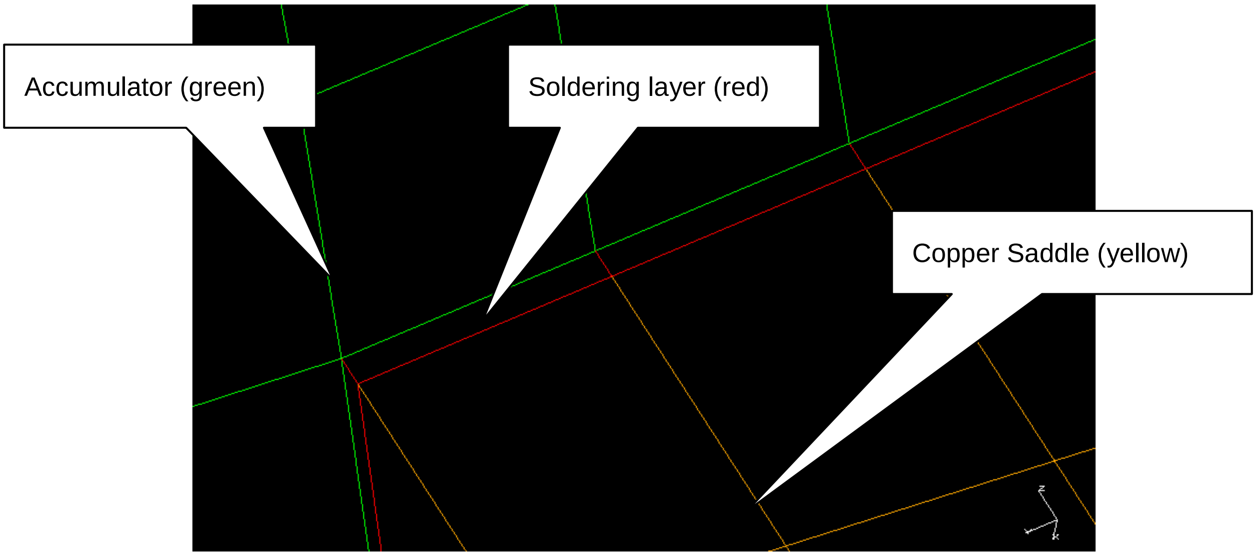


Figure 4-4 Accumulator Assembly FEM

Accumulator Heat Assembly (Figure 4-5~Figure4-8)

Accumulator Heat Pipe:

The Model is fully meshed with hexahedral 3D Solid elements.

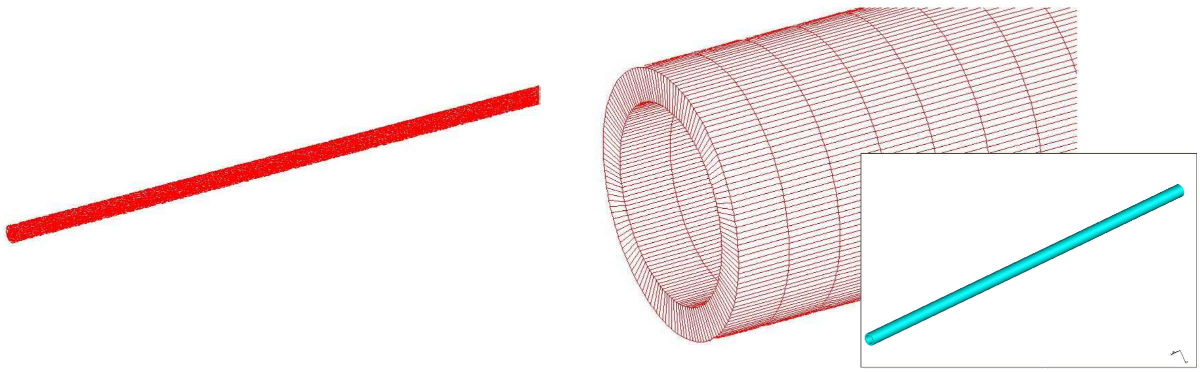


Figure 4-5 Accumulator Heat Pipe FEM

Accumulator Heat (Figure 4-6)

The Model is fully meshed with tetrahedron 3D Solid elements.

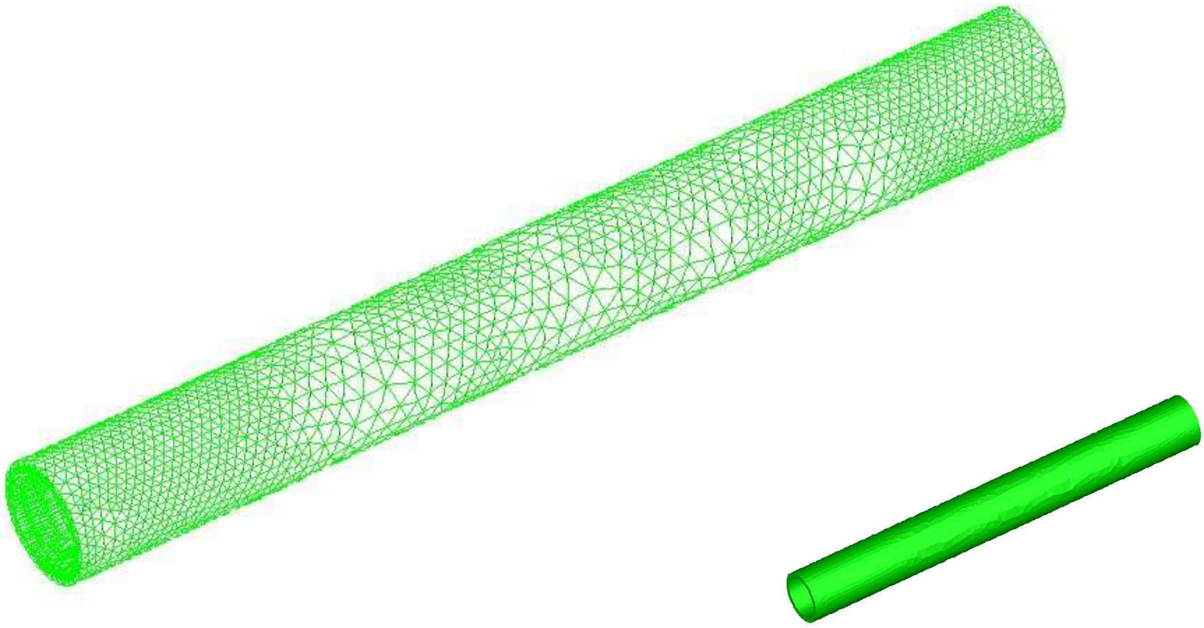


Figure 4-6 Accumulator Heat FEM

Thermostates Saddle & Thermostates (Figure 4-7)

The Model is fully meshed with tetrahedron 3D Solid elements.

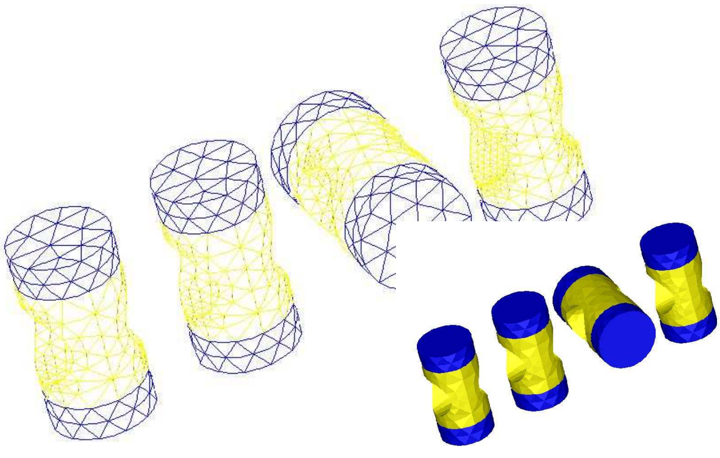


Figure 4-7 Thermostates Saddle & Thermostates FEM

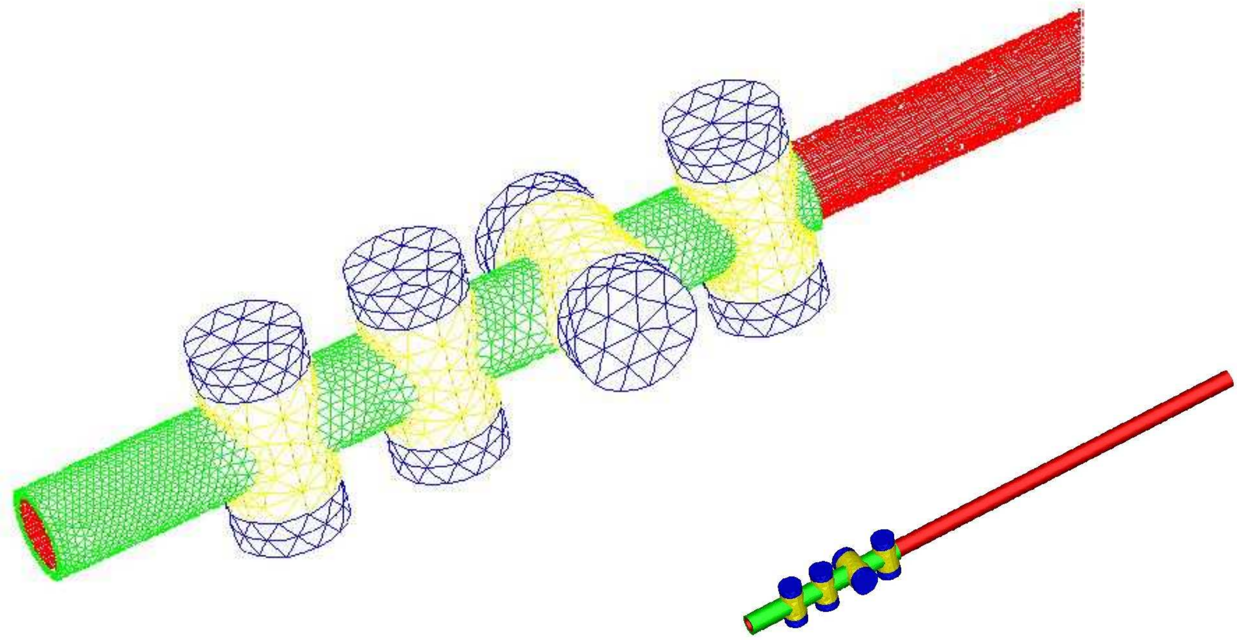


Figure 4-8 Accumulator Heat Assembly FEM

Fixed Bracket Clamp Assembly (Figure 4-9~Figure4-11)

Fixed Bracket Clamp:

The Model is fully meshed with tetrahedron 3D Solid elements.

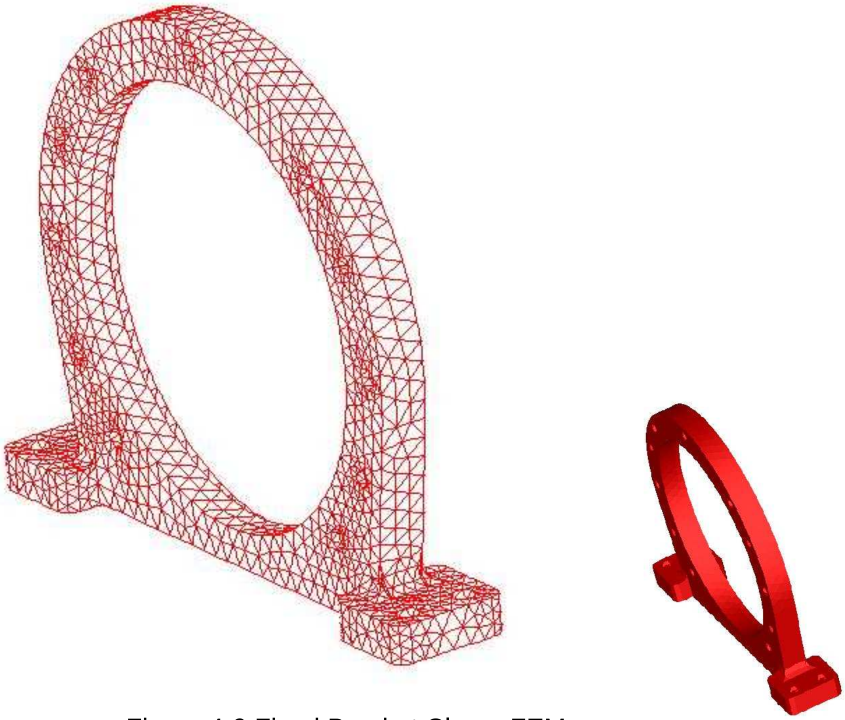


Figure 4-9 Fixed Bracket Clamp FEM

Fixed Clamp Collar & Wedge (Figure 4-10)

The Model is fully meshed with tetrahedron & hexahedral 3D Solid elements.

Figure 4-10 Fixed Bracket Clamp Collar & Wedge FEM

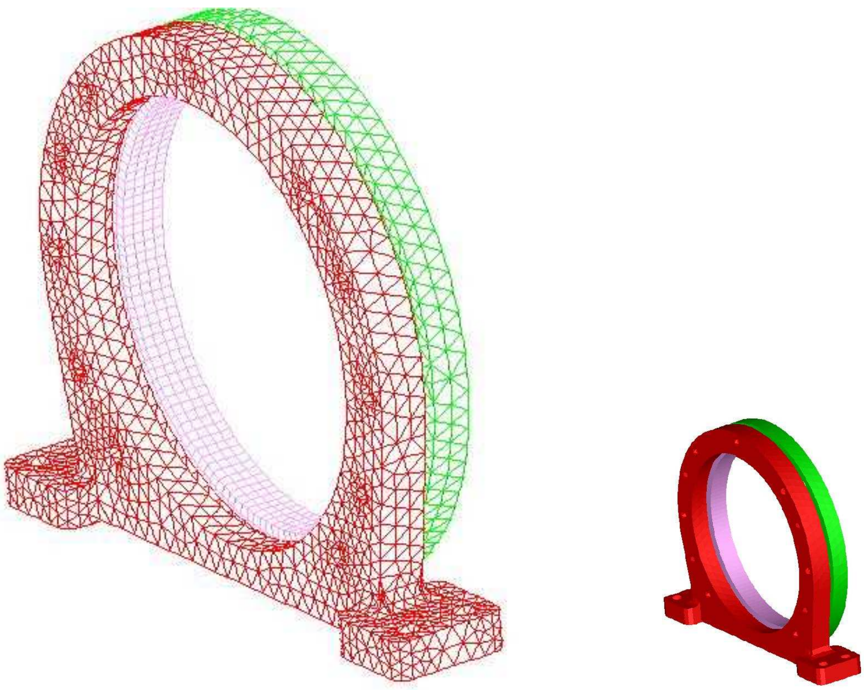
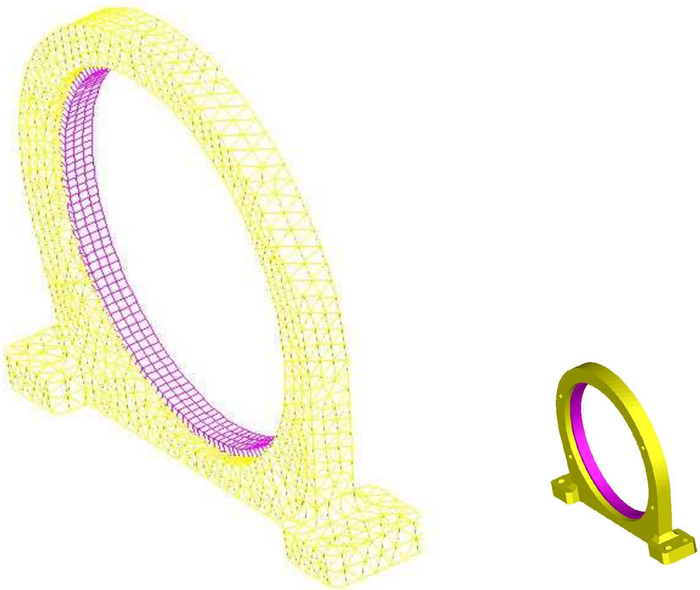


Figure 4-11 Fixed Bracket Clamp & Collar & Wedge Assembly FEM

Slide Bracket assembly (Figure 4-12)

The Model is fully meshed with tetrahedron & hexahedral 3D Solid elements.



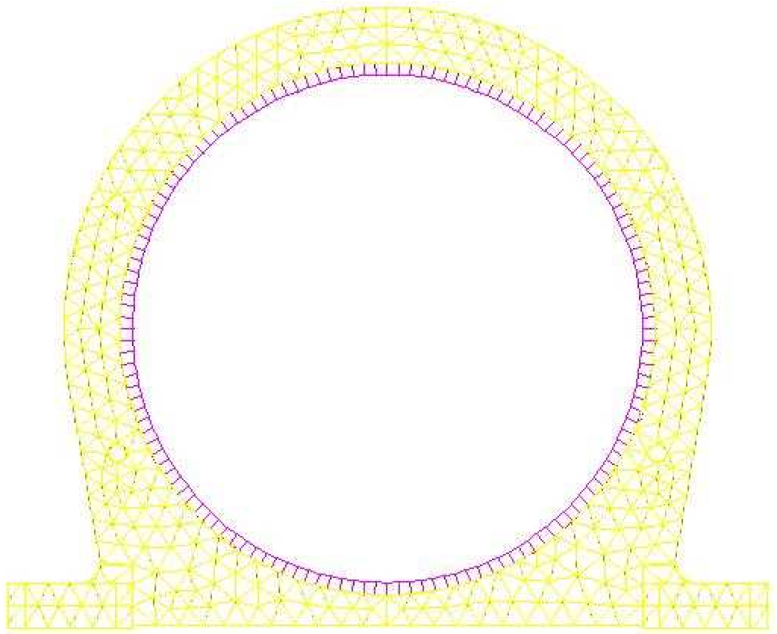


Figure 4-12 Slide Bracket Assembly FEM

Peltier HX Assembly (Figure 4-13~Figure4-16)

Peltier Heat Exchanger:

The Model is fully meshed with hexahedral 3D Solid elements.

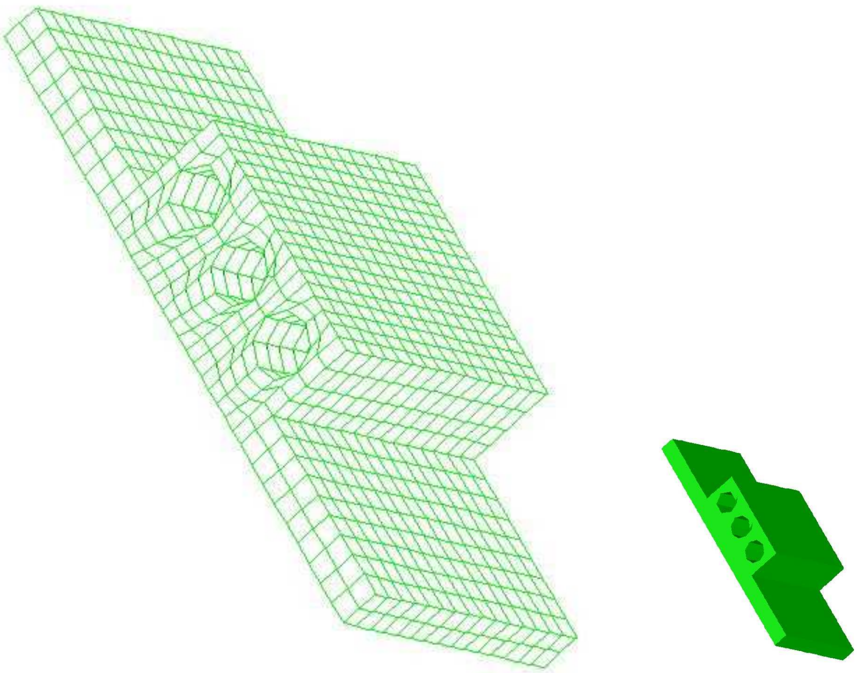


Figure 4-13 Peltier Heat Exchanger

Disk Spring Press (Figure 4-14)

The Model is fully meshed with tetrahedron 3D Solid elements.

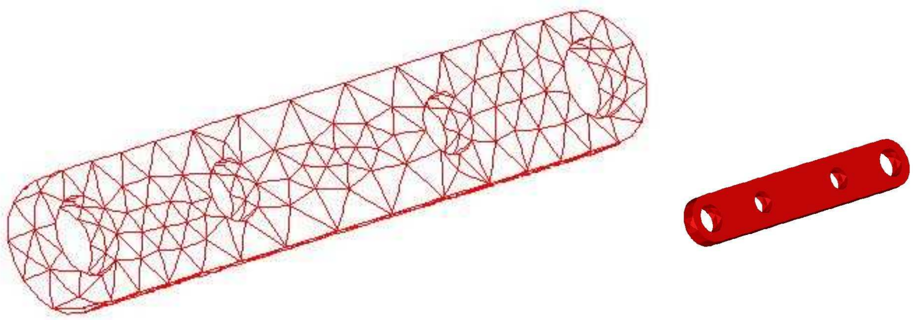


Figure 4-14 Disk Spring Press FEM

Disk Spring support (Figure 4-15)

The Model is fully meshed with hexahedral 3D Solid elements.

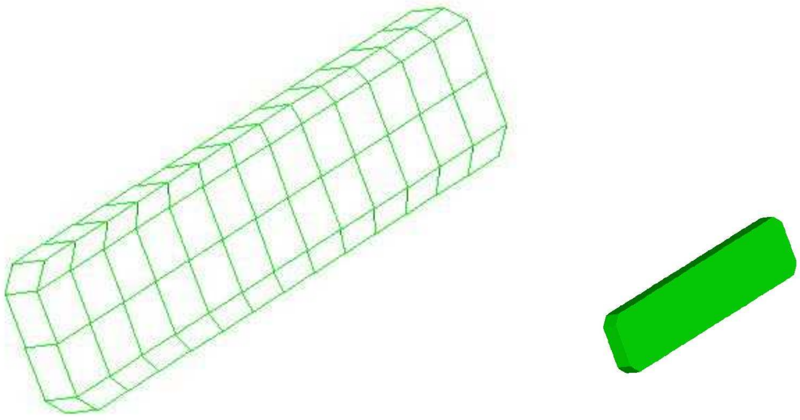


Figure 4-15 Disk Spring support FEM

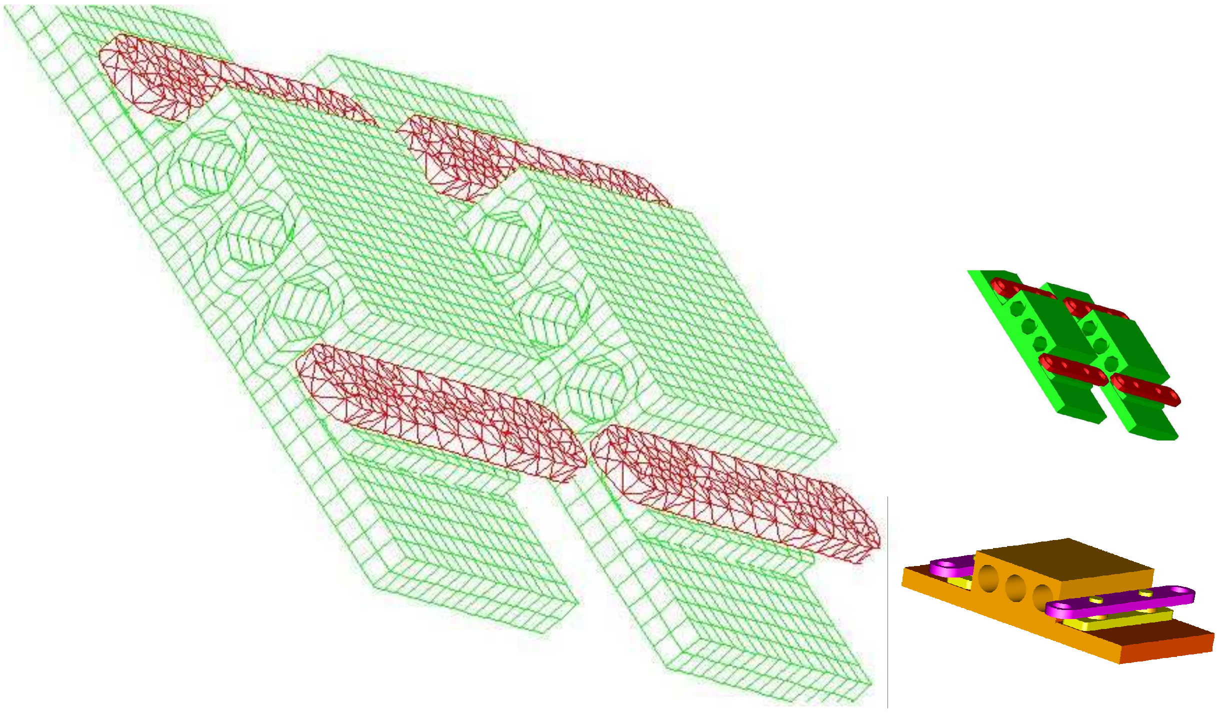


Figure 4-16 Peltier HX Assembly FEM

THERMASTAT (Figure 4-17)

The Model is fully meshed with tetrahedron 3D Solid elements.

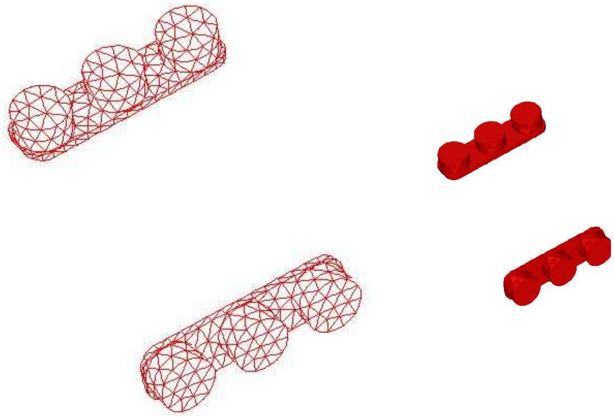


Figure 4-17 THERMASTAT FEM

Peltier Pipes (Figure 4-18)

The model is fully meshed with beam elements. The cross section is using the exactly data of the tube.

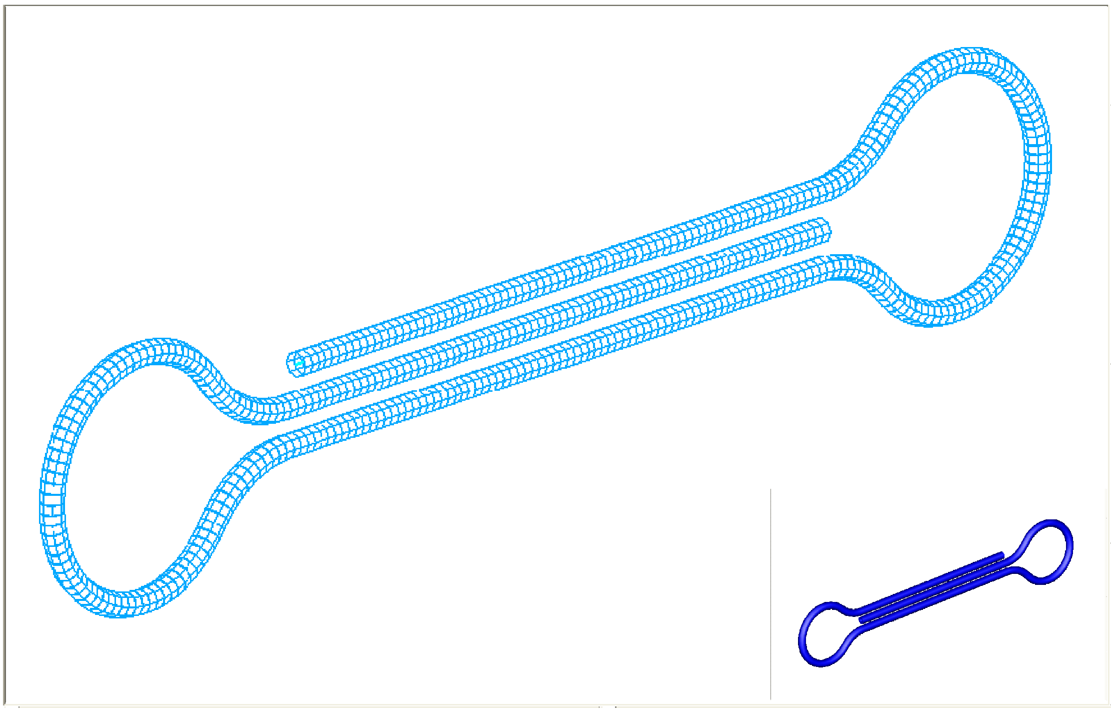


Figure 4-18 Peltier Pipes FEM

Peltier Pipe Fixer (Figure 4-19)

The Model is fully meshed with tetrahedron 3D Solid elements.

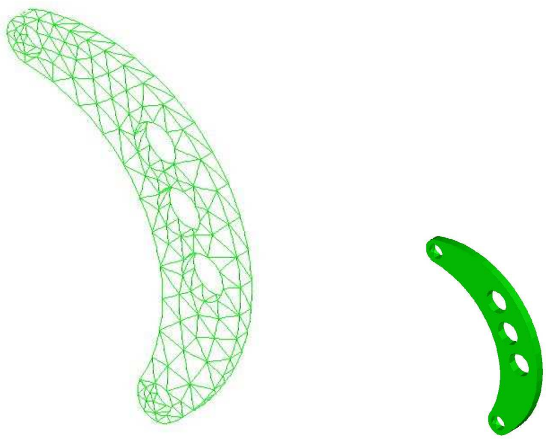


Figure 4-19 Peltier Pipe Fixer FEM

Base Plate (Figure 4-20)

The Model is fully meshed with tetrahedron & hexahedral 3D Solid elements.

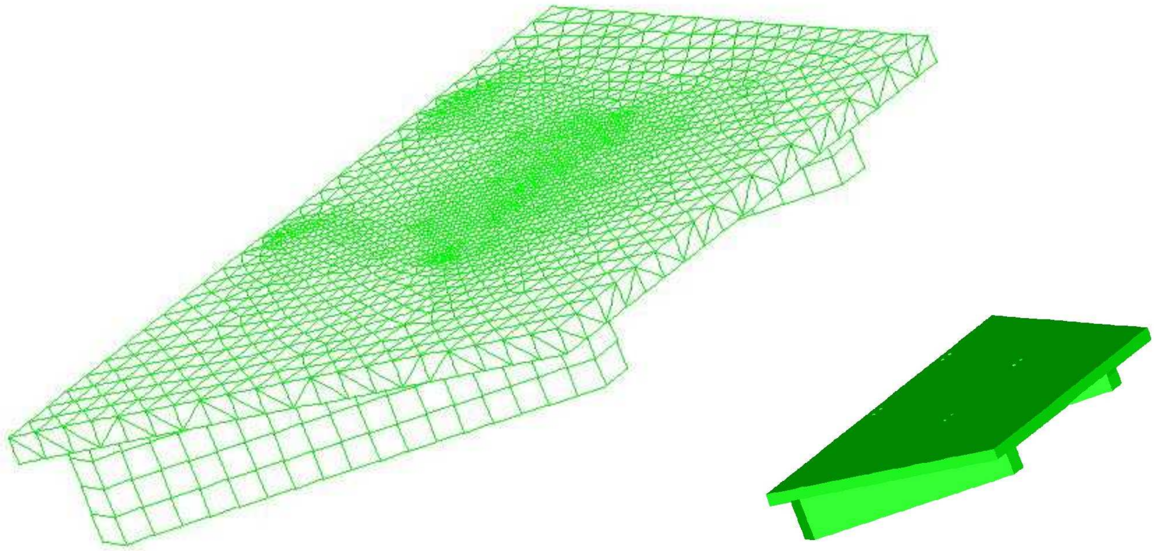


Figure 4-20 Base Plate FEM

4.1.2 FEM Assembly and Connection

Figure 4-21 shows the FEM of the assembly. Totally there are 287479 **nodes** and 170559 **elements.** Different parts of the model are connected together by different ways. The details are described as follow:

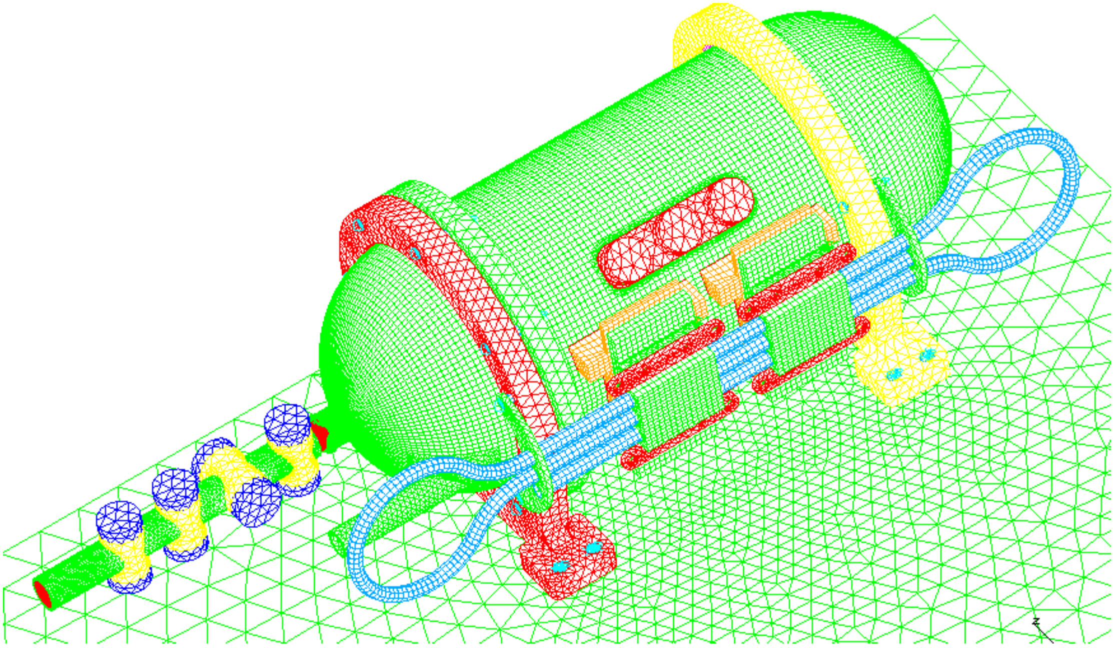
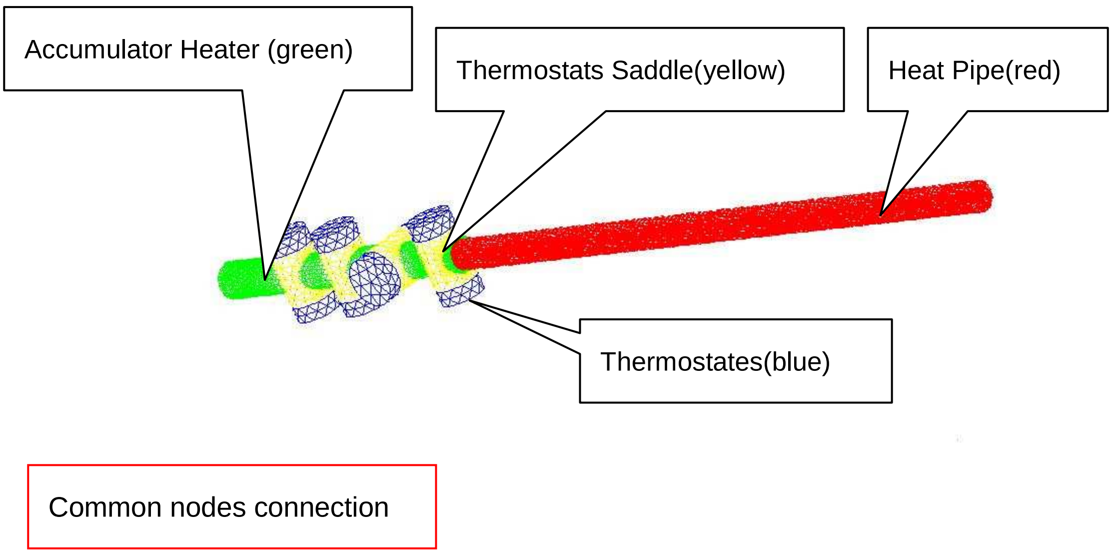


Figure 4-21 Final assembly FEM

Accumulator Heat Pipe& Accumulator Heater& Thermostats Saddle &Thermostates (Figure 4-22)

These four parts are connected by common nodes. All of the nodes on the welding areas are shared by two different parts. See figure 4-22 for more details.



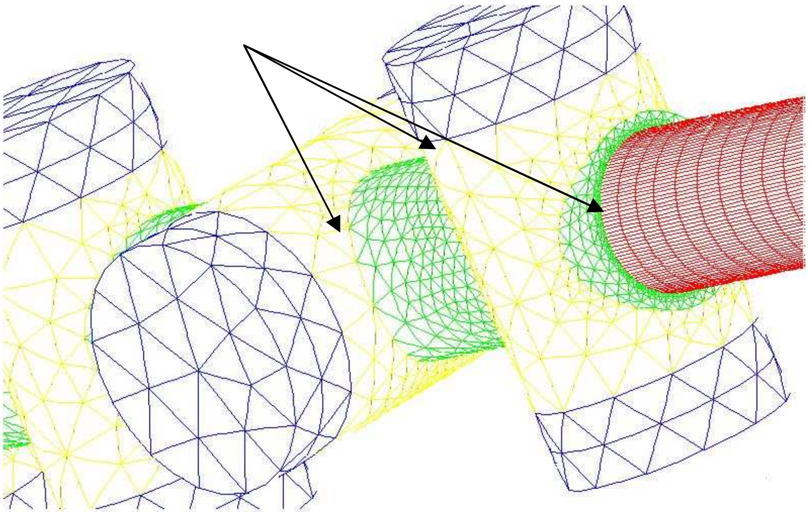
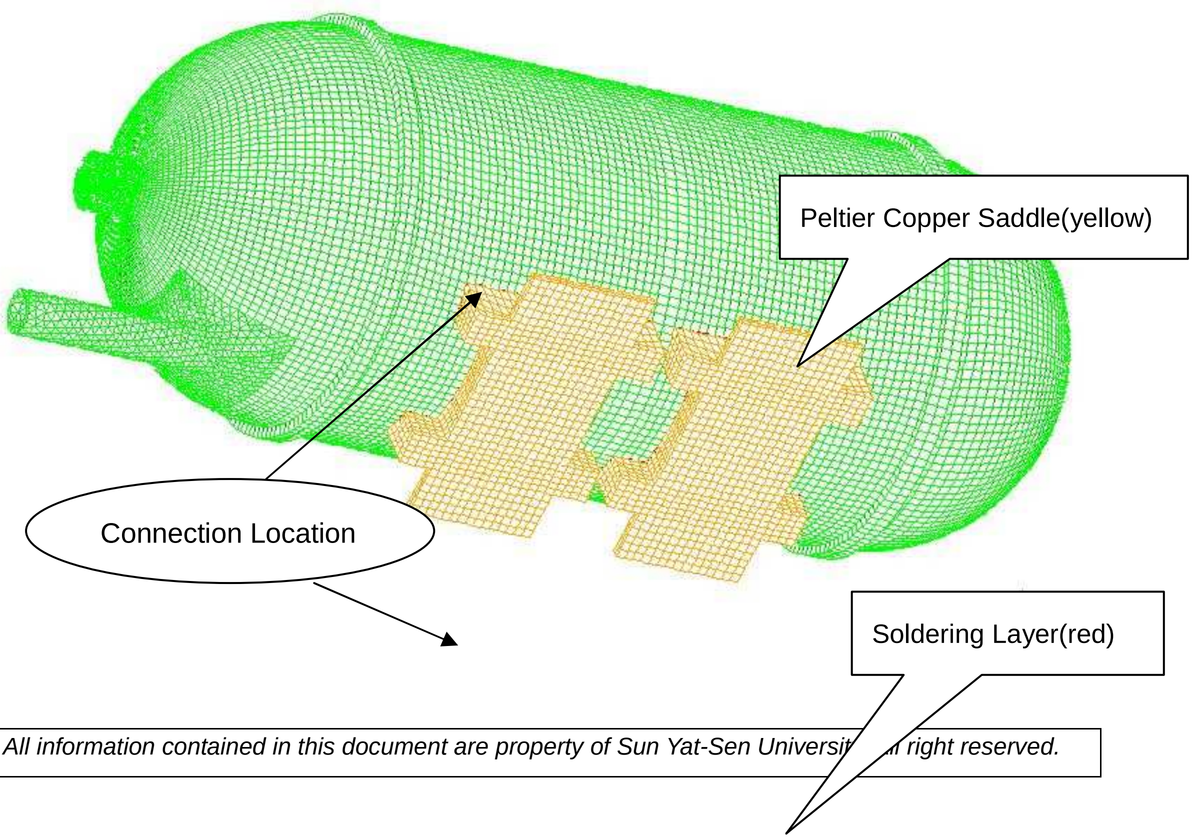


Figure 4-22 Accumulator Heat Pipe& Accumulator Heater& Thermostats Saddle &Thermostates Common nodes connection

Accumulator& Soldering layer& Peltier Copper Saddle (Figure 4-23)

These four parts are connected by common nodes. All of the nodes on the welding areas are shared by two different parts. See figure 4-23 for more details.



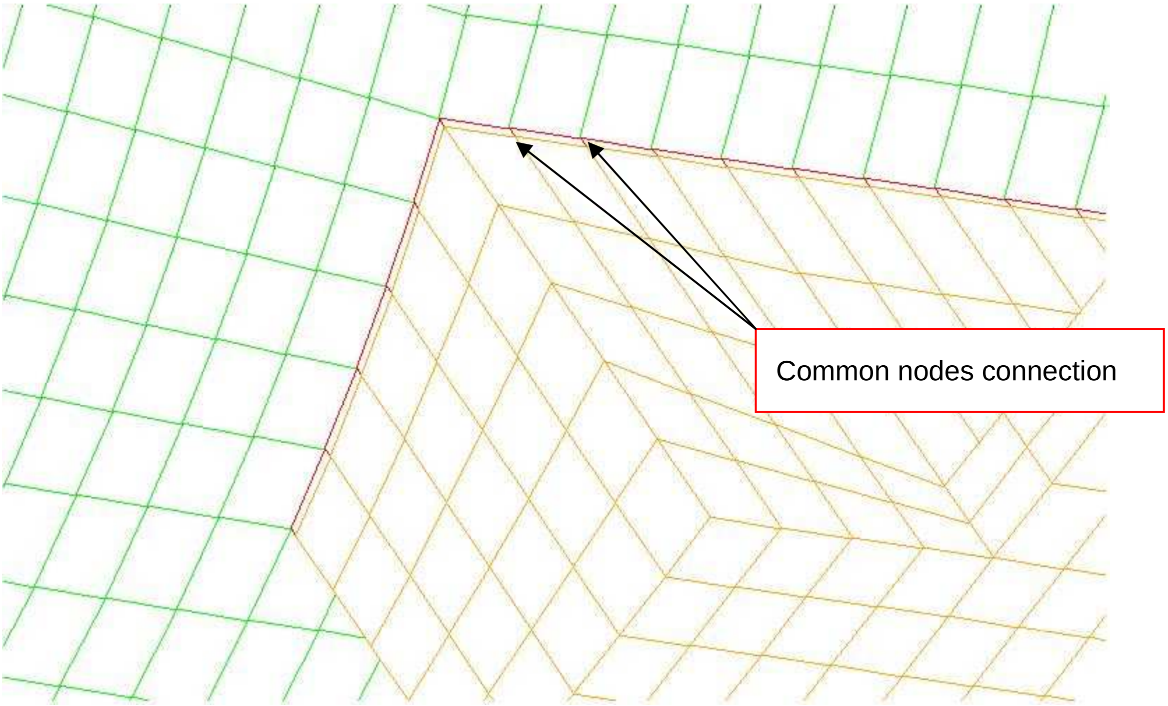


Figure 4-23 Accumulator& Soldering layer& Peltier Copper Saddle Common nodes connection

Accumulator Assembly & Heater Pipe Assembly(Figure 4-24)

These two parts are connected by connect elements. These connect elements in a circle is for welding simulation. See figure 4-24 for more details.

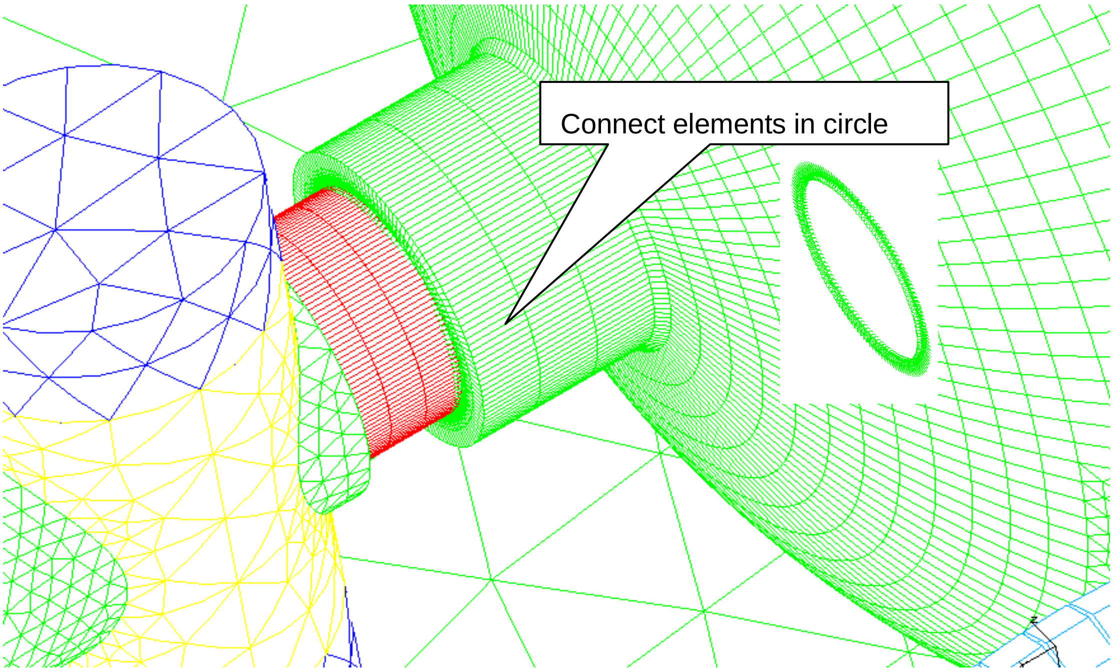


Figure 4-24 connect between Accumulator Assembly & Heater Pipe Assembly

Clamp Bracket & ACCU(Figure4-25)

The Clamp and the Collar are connected by the bolts connection at corresponding locations. The Collar is connected to accumulator by coupled DOF at coincident nodes, the restraints of DOF is in a circle.

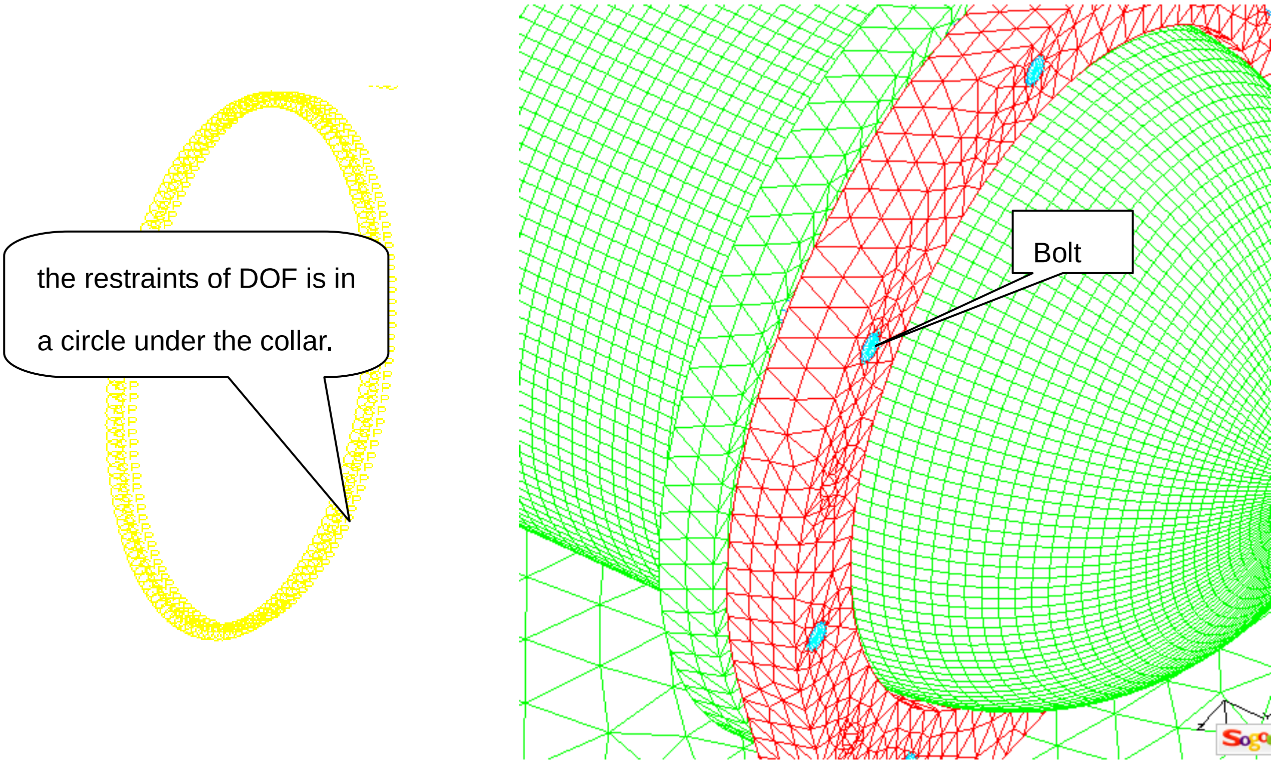


Figure 4-25 connect between Clamp Bracket & ACCU

Bracket & Base Plate (Figure 4-26)

The brackets of Accumulator are connected to the base plate by the bolts connection at corresponding locations.

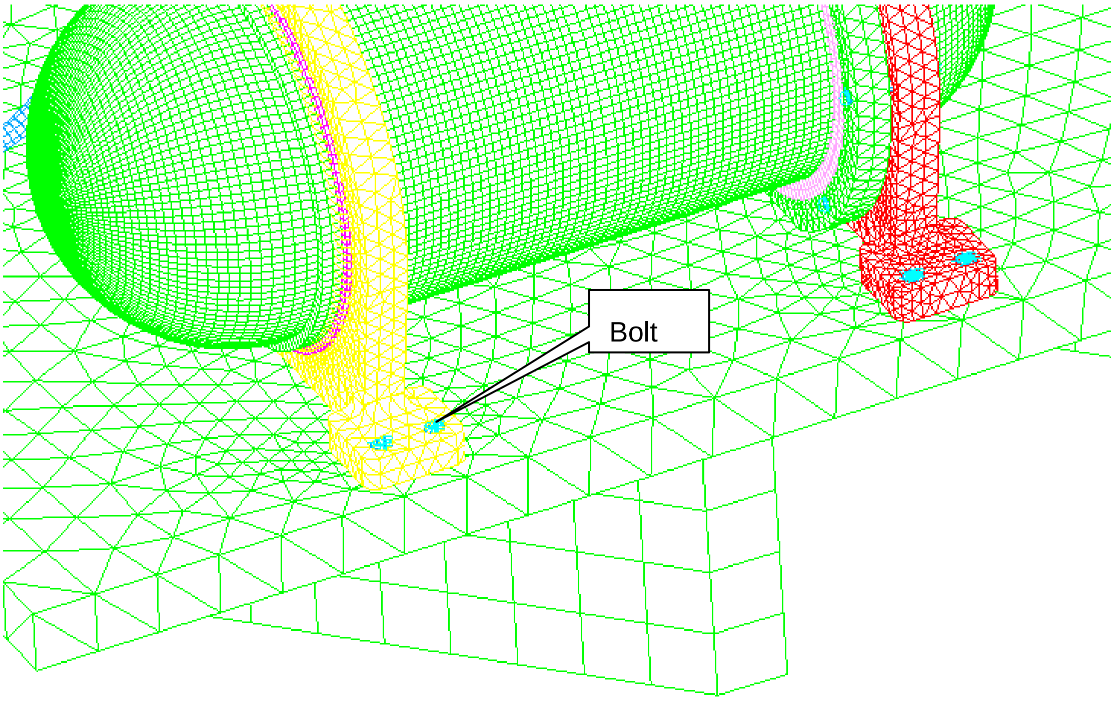


Figure 4-26 connect between Bracket & Base Plate

Pelter HX & ACCU&THERMASTAT (Figure 4-27)

The Peltier HX is connected to the Peltier Saddle by bolt connection at the bolts' corresponding location. The spring support on HX is connected to the HX by connection elements. The THERMASTAT is connected to ACCU by connection elements.

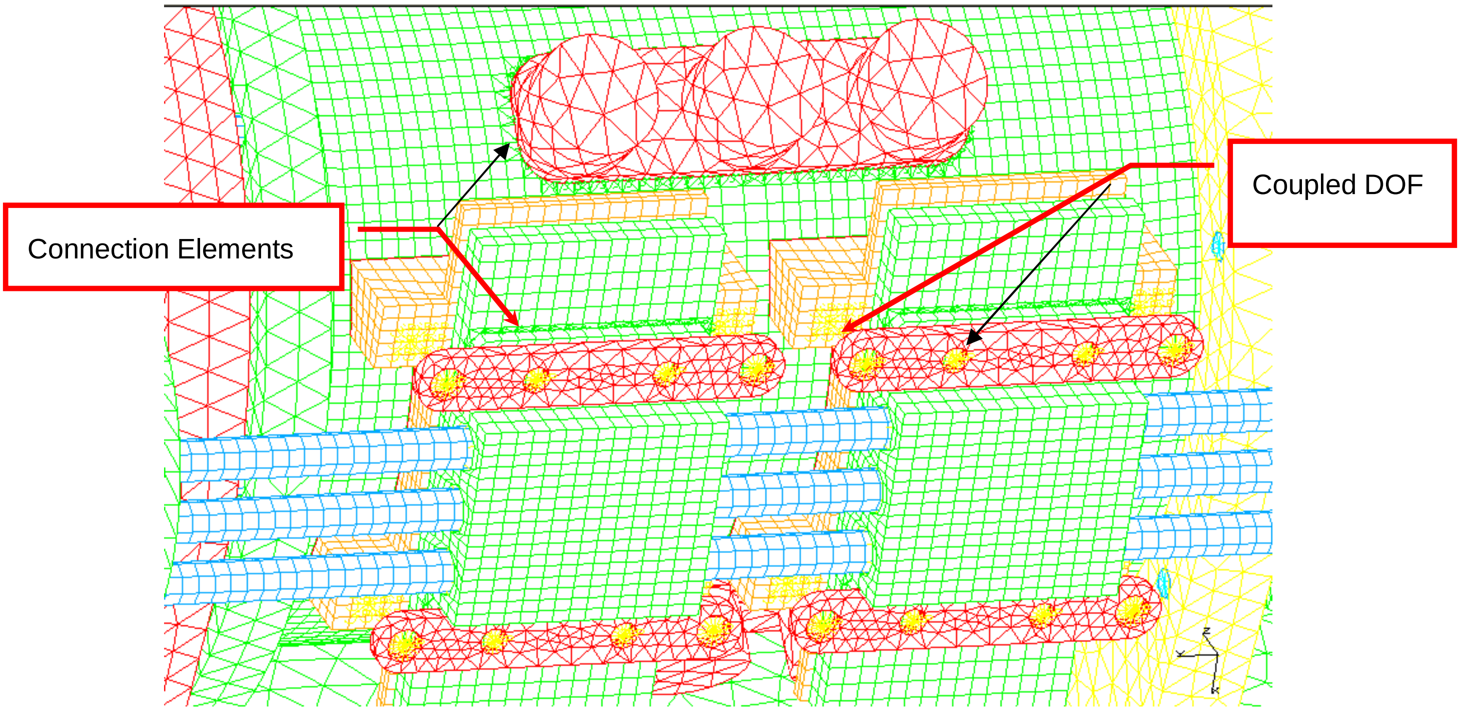


Figure 4-27 connect between Pelter HX & ACCU&THERMASTAT

Slide Bracket & ACCU (Figure 4-28)

The slide is connected to the ACCU by coupled DOF (axial direction free, radial direction coupled)

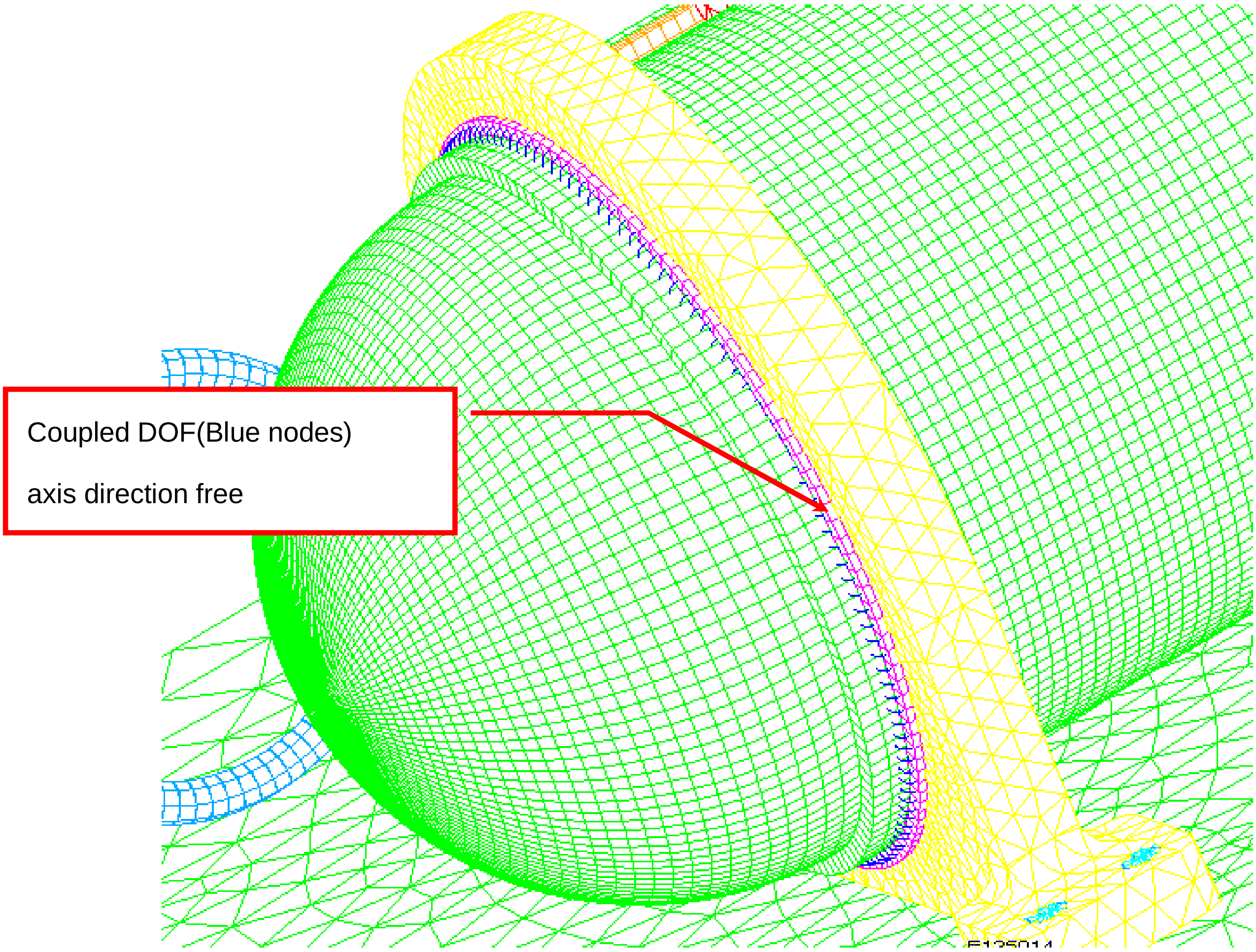


Figure 4-28 connect between Slide Bracket & ACCU

4.2 Constraints and Loads

4.2.1 Constraints

The bolts' locations in the base plate are restrained. See Figure 4-29

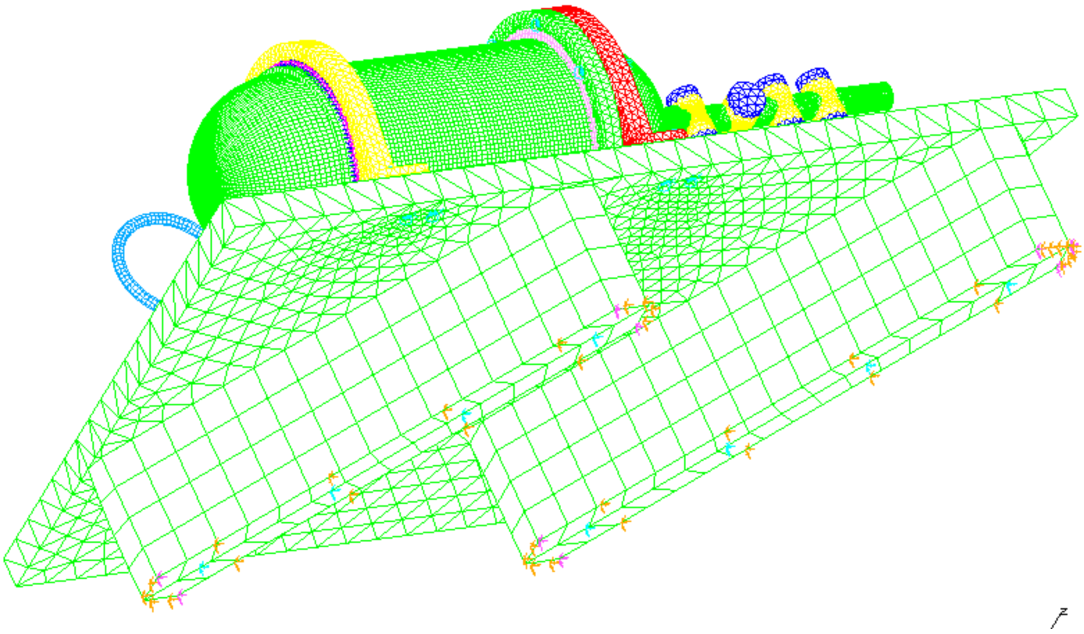


Figure 4-29 Base Plate Restraint

4.2.2 Loads

According to document "Accumulator verification load cases summary_rev3.doc"[RD5], there are two main load cases needed to be verified for the accumulator's structural analysis.

The first one is the **launching/landing load cases**. It consists of three kinds of loads – pressure, acceleration and temperature (Table 4-4). These loads' details are described from chapter 4.2.3 to 4.2.7 . In the calculation, only the red case in Table 4-4 is performed with considering the pressure load in the second case (green case) is much smaller compared to the first case and produces smaller stress . By our previous calculation[RD6] [RD7], stress caused by the bigger pressure is the main portion of the final stress.

Table 4-4 Load combinations during launching/landing

	Acceleration loads
Pressure load 160 bar	+65 ℃ + possible CTE stress
Pressure load 10.1 bar	-40 ℃ + possible CTE stress

The second one is the **in orbit load cases**. It consists of two kinds of loads – pressure and thermal stress load due to heating (Table 4-5). The loads' details are described from chapter 4.2.3 to 4.2.7 .

In the calculation, only the red case in Table 4-5 is performed with considering the pressure load in the green case is much smaller compared to the first two cases.

Table 4-5 Load combinations in orbit

	Thermal stress load due to heating
Pressure load 160 bar	Maximum gradient due to HP wire heaters
Pressure load 160 bar	Maximum gradient due to Peltier cooler dissipation
Pressure load 51 bar	Maximum gradient between operating accu at setpoint T=+15 ℃ and the cold fluid (-40 ℃) in the Peltier HX tubes

4.2.3 Acceleration

±40g acceleration is applied in one direction with ±10g simultaneously applied in the other two directions according to Document JSC-28792. Therefore six acceleration cases are calculated to verify the stress of the model while the missile is launching or landing. They are all listed in Table 4-6.

4.2.4 Temperature

Considering the fact that the TTCS boxes are well insulated, the TTCS accumulator will have a uniform temperature during launching and descent. This uniform temperature distribution will produce stress at the interfaces between different materials (different CTE); so these stresses should be evaluated.

Reference temperature: 21.85 ^{o}C

Highest Launching/Landing Uniform Temperature: 65 ^{o}C

Table 4-6 Six acceleration cases

Load Case	Acceleration (g)		
	x	y	z
1	10	**40**	10
2	**40**	10	10
3	10	10	**40**
4	-10	**40**	-10
5	10	**-40**	-10
6	-10	**-40**	10

But considering the results attained from the previous calculations, the temperature load seems to have some release effect for the model's stress calculation. That means if the temperature load is applied, it will reduce the Max stress value of the model. And this is not recommended in the simulation. So in the calculation, the temperature load in the launching/landing cases is not applied.

4.2.5 Pressure

There are two pressure vessels in the model, and the pressure (MDP) applied on them are listed as follow:

AHP: 57bar inside the vessels

Accumulator: 160bar inside the vessels (65 ^{o}C)

4.2.6 Thermal stress load due to heating

The reference temperature (assembly temperature) in the calculation is 21.85℃.

The most critical cases of the temperature gradient are defined to be:

HOT(Red case in Table 4-5)

1) When Accumulator Emergency Heaters and Accumulator control heaters are switched on full power, the heat pipe is still operating but the loop is not running.

   Take the temperature profile at the time where the third Thermal Switch on the heat pipe will switch. This induces the worst case temperature profile. **(HP TS Switched Case) the temperature distribution is shown in Figure 6-1**

2) When the Peltier elements are all dissipating maximum power and the loop is not running. Take the temperature profile close to the point where the Thermal Switches switch the heaters off. **(Peltier TS Switched Case) the temperature distribution is shown in Figure 6-2**

3) The combination of cases 1 and 2. For this Case, there are two sub cases for it. Because when the Peltier and the Heater are operating together at the same time, the HP will reach the set point of 55 ℃ first and the TS on it will turn heaters down while the Peltiers are still operating. And when the Peltier's temperature reaches the set point of 55 ℃, the HP's temperature will be lower than 55 ℃. So this case has to divide into two sub case

   i. HP reaches 55 ℃, Peltier lower than 55 ℃ **(Combined Case – HP Max) the temperature distribution is shown in Figure 6-3**

   ii. HP lower than 55 ℃, Peltier reaches 55 ℃ **(Combined Case – Peltier Max) the temperature distribution is shown in Figure 6-4**

COLD (Green case in Table 4-5)

1) Accumulator runs at +15 ℃ and cold fluid (-40 ° C) runs through the tube.

Being the pressure load in the **COLD** case negligible compared to the first two cases, the green case is not performed in the calculation.

The thermal analysis for the critical hot cases in orbit about accumulator assembly is described in Chapter 6.1 . And the results of temperature distribution in these critical cases are used as the input for the thermal stress calculation in Chapter 6.2 and 6.3 .

4.2.7 Load Combination

For the **Launching/Landing load cases**, Eight Acceleration cases and pressure load are combined.

For the **in orbit load cases**, pressure load and three hot cases of temperature gradient are combined.

4.3 Calculation Assumption

1) This calculation is based on linear thermal properties;
2) Thermal expansion coefficient is a constant (actually it is a function of temperature);
3) Materials mechanical properties take the value at room temperature;

4.4 Formula of MoS and Factor of Safety

The formulas below are used to calculate the MoS for each material in this document.

$$MS_{yeld} = \frac{Yield\ \ Stress}{FS_y \times Limit\ \ Stress\,(Von\,Mises)} - 1$$

$$MS_{ult} = \frac{Ultimate\ \ Stress}{FS_{ult} \times Limit\ \ Stress\,(Max\,\Pr incipal)} - 1$$

With $FS = Factor\ \ of\ \ Safety$

And about the Factor of safety for each component:

There are two kinds of components in accumulator assembly (Pressure component and non-Pressure component). And considering that these components have different requirements, the factor of safety of these components should be considered separately. The FS for each component is shown in Table 4-7 according to Document JSC-28792.

Pressure system criteria: $FS_y = 1.5\ /\ FS_{ult} = 2.5 \quad or \quad 4$

Normal system criteria: $FS_y = 1.25 / FS_{ult} = 2$

Table 4-7 Factor of Safety for each component

Part	Factor of Safety	
	Yield	Ultimate
Accumulator	1.5	2.5
Heat Pipe	1.5	4
CLAMP Assembly		
CLAMP	1.25	2
CLAMP_COLLAR	1.25	2
CLAMP_WEDGE	1.25	2
HE Pipe		
Peltier Pipe	1.25	2
PELTIER HE 1	1.25	2
PELTIER HE 2	1.25	2
Pipe Fix A	1.25	2
Pipe Fix B	1.25	2
PELTIER Assembly		
Copper Saddle	1.25	2
Press	1.25	2
Spring Support	1.25	2
SLIDE Assembly		
SLIDE RING	1.25	2
SLIDE	1.25	2
TS Saddle	1.25	2
Heater	1.25	2
Soldering material	1.25	2

5. STRUCTURE ANALYSIS FOR LAUNCHING /LANDING LOAD CASES

5.1 Static Analysis for launching/landing load cases

The calculated maximum stress and displacement for all materials under launching or landing load cases are list from Table 5-1 to Table 5-9. The Yield and Ultimate margins of safety (MoS) are listed in the same table. Accumulator is the most stressed structure. AHP, Heater and TS Saddle are the structures where the largest displacements occur.

The Soldering Layer connecting the copper saddle and accumulator has passed through the test so it is not included in the MoS analysis. The bolts connecting accumulator brackets and base plate have been calculated and analyzed in the TTCB's structural analysis document[RD3]. Although these bolts are included for the FEM modeling in this calculation, these bolts are not included for MoS analysis.

Compared with the results in RD7, peltier saddle's Max Stress values have been reduced by importing the soldering material layer. The soldering material layer is map meshed with 3D Solid elements.

The loading X、Y and Z direction are showed in Fig.5-1. The Restrains at Basepalte bolts locations are listed at table 5-1.

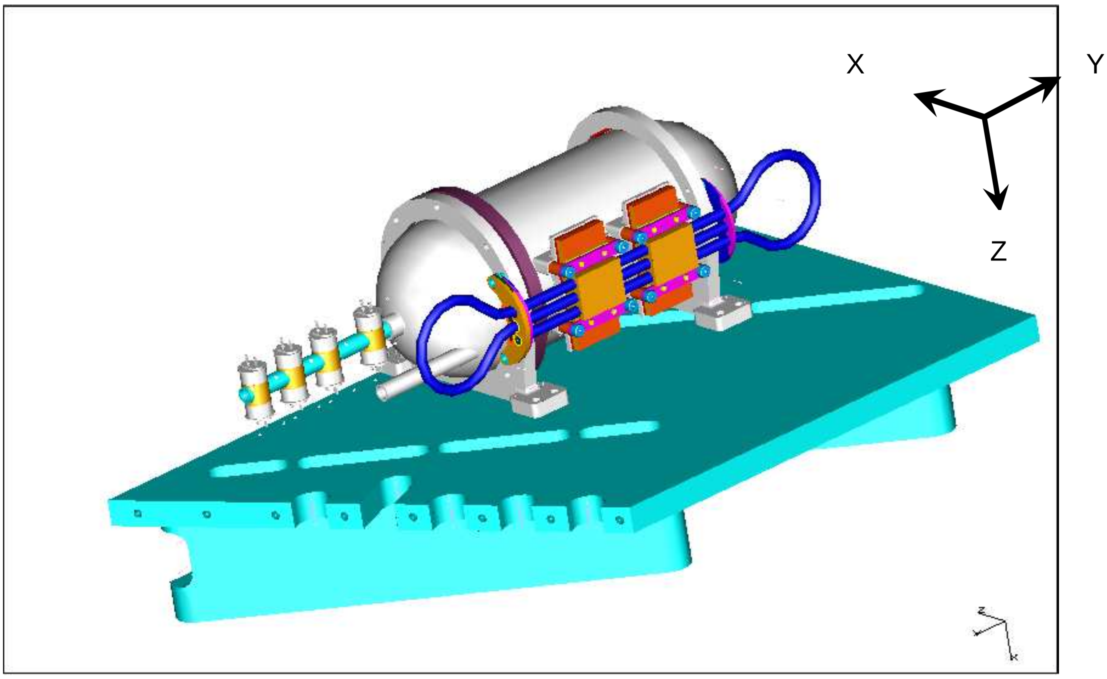


Figure 5-1 Static Analysis: Acceleration Direction

Table 5-1 The Restrains at Basepalte bolts location

Restraints *at Base Plate Bolts Locations*					
Ux	Uy	Uz	Rx	Ry	Rz
0	0	0	0	0	0

5.1.1 FEM model stress and displacement under Pressure and Six acceleration cases

Explanations:

Pressure: Present 160 and 57 Bar Pressure for accumulator and Heat Pipe

ACCX40+: Present acceleration in X direction, value is 40g

ACCX40-: Present acceleration in -X direction, value is 40g

ACCY40+: Present acceleration in Y direction, value is 40g

ACCY40-: Present acceleration in -Y direction, value is 40g

ACCZ40+: Present acceleration in Z direction, value is 40g

ACCZ40-: Present acceleration in -Z direction, value is 40g

ACCX10+: Present acceleration in X direction, value is 10g

ACCX10-: Present acceleration in -X direction, value is 10g

ACCY10+: Present acceleration in Y direction, value is 10g

ACCY10-: Present acceleration in -Y direction, value is 10g

ACCZ10+: Present acceleration in Z direction, value is 10g

ACCZ10-: Present acceleration in -Z direction, value is 10g

5.1.2 Stress: Von Mises under Pressure of 160&57 Bar case.

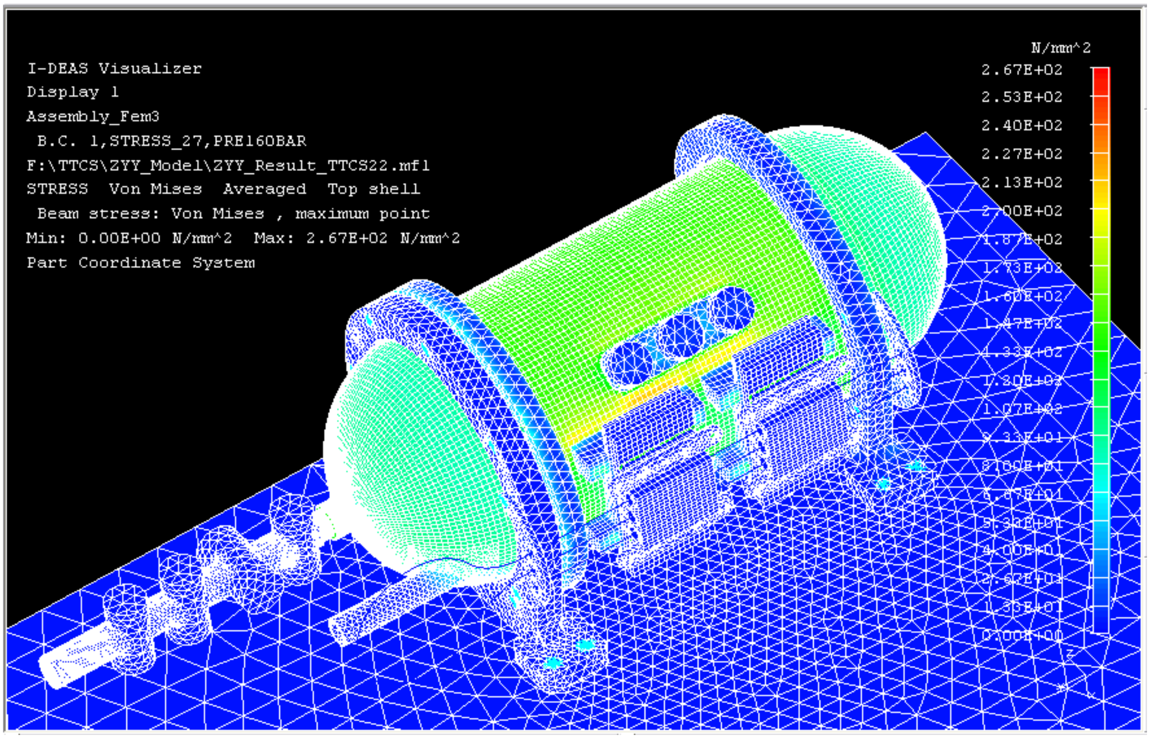


Figure 5-2 Static Analysis: Stress: 160&57 Bar Pressure

5.1.3 Stress: Von Mises under Six accelerations cases.

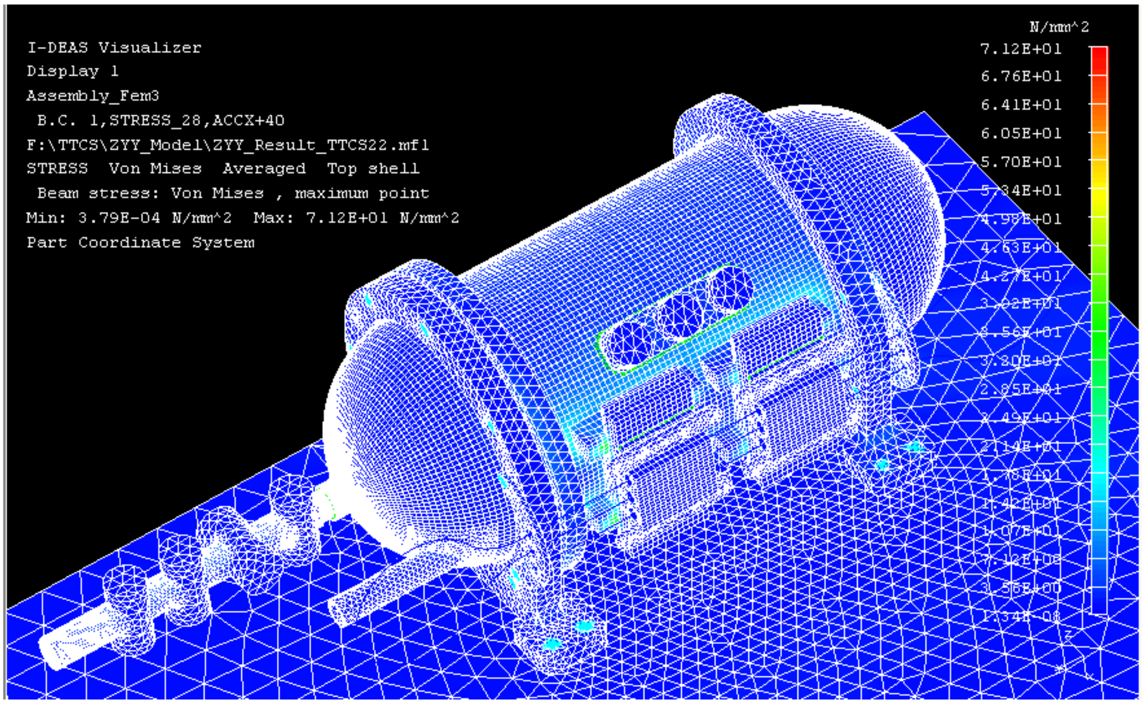


Figure 5-3 Static Analysis: Stress: Acceleration in X direction 40g

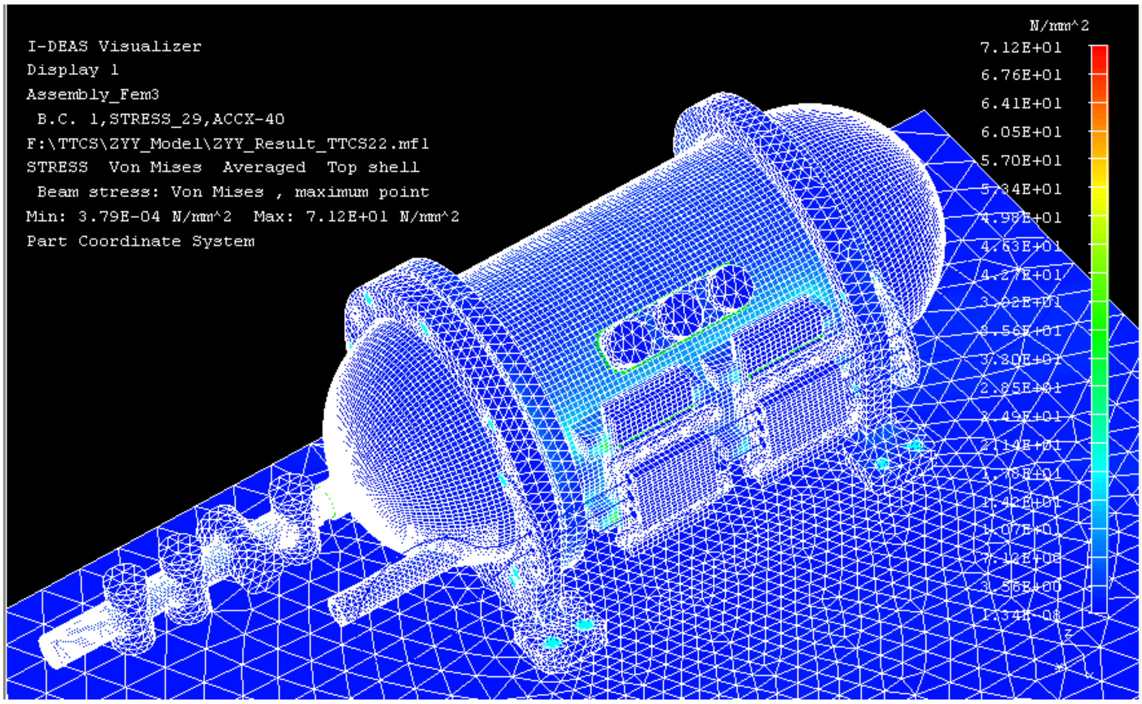


Figure 5-4 Static Analysis: Stress: Acceleration in -X direction 40g

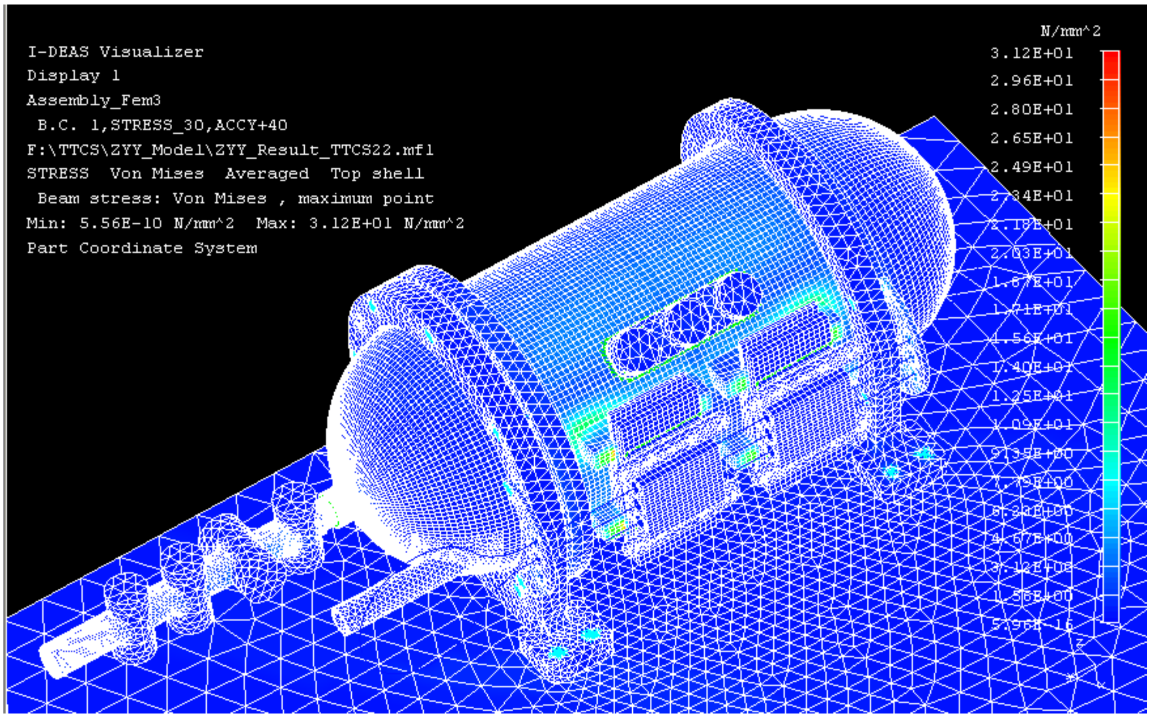


Figure 5-5 Static Analysis: Stress: Acceleration in Y direction 40g

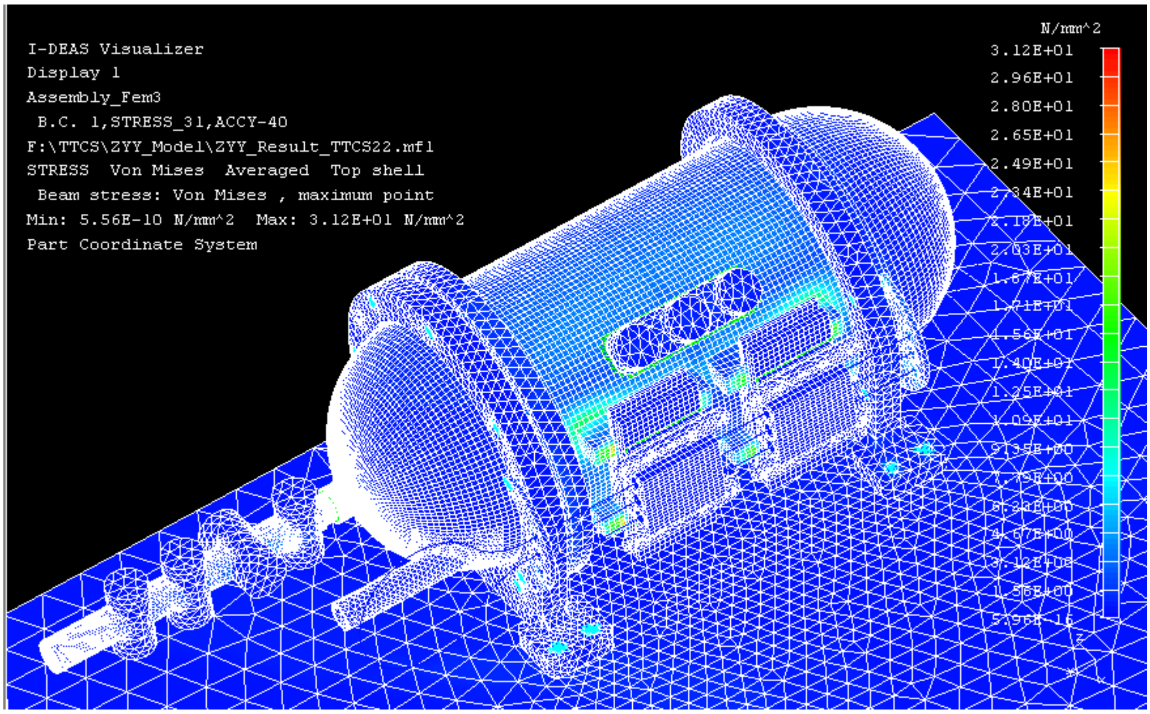


Figure 5-6 Static Analysis: Stress: Acceleration in -Y direction 40g

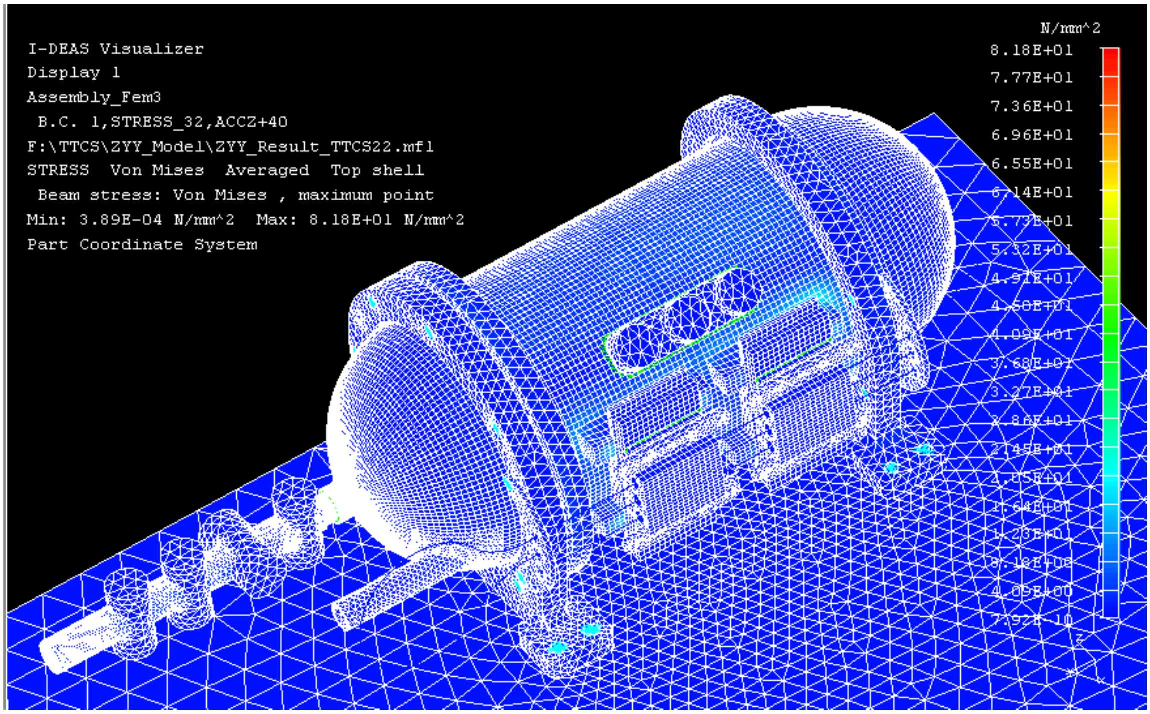


Figure 5-7 Static Analysis: Stress: Acceleration in Z direction 40g

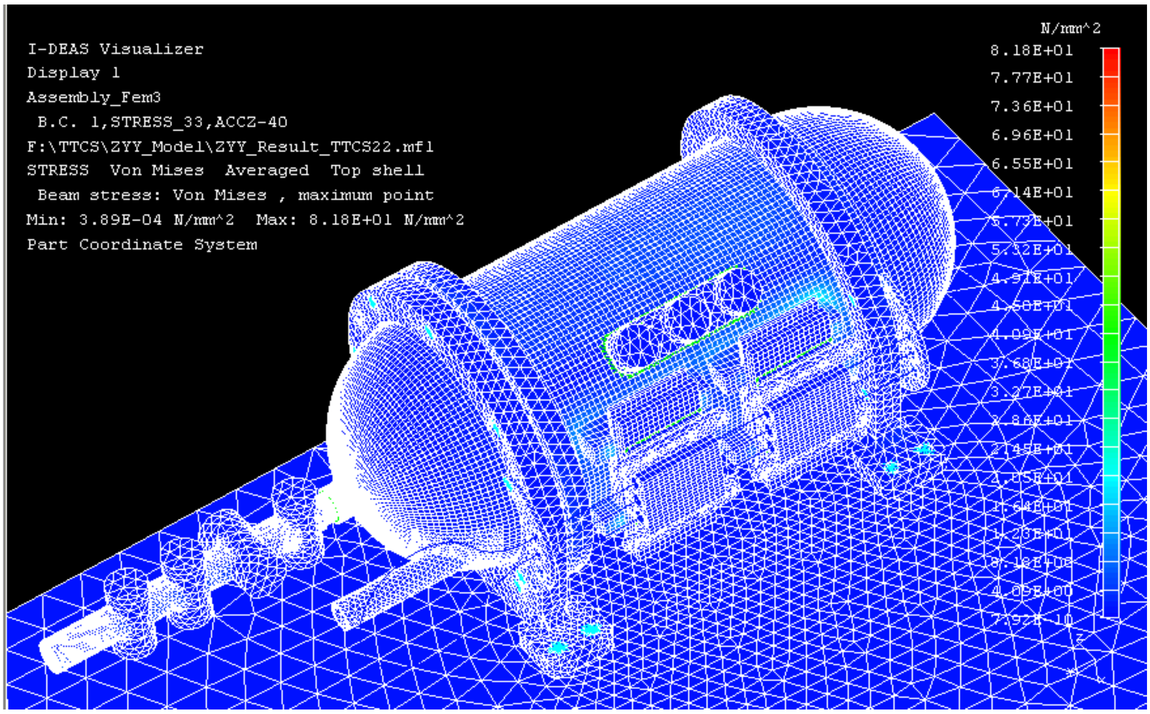


Figure 5-8 Static Analysis: Stress: Acceleration in -Z direction 40g

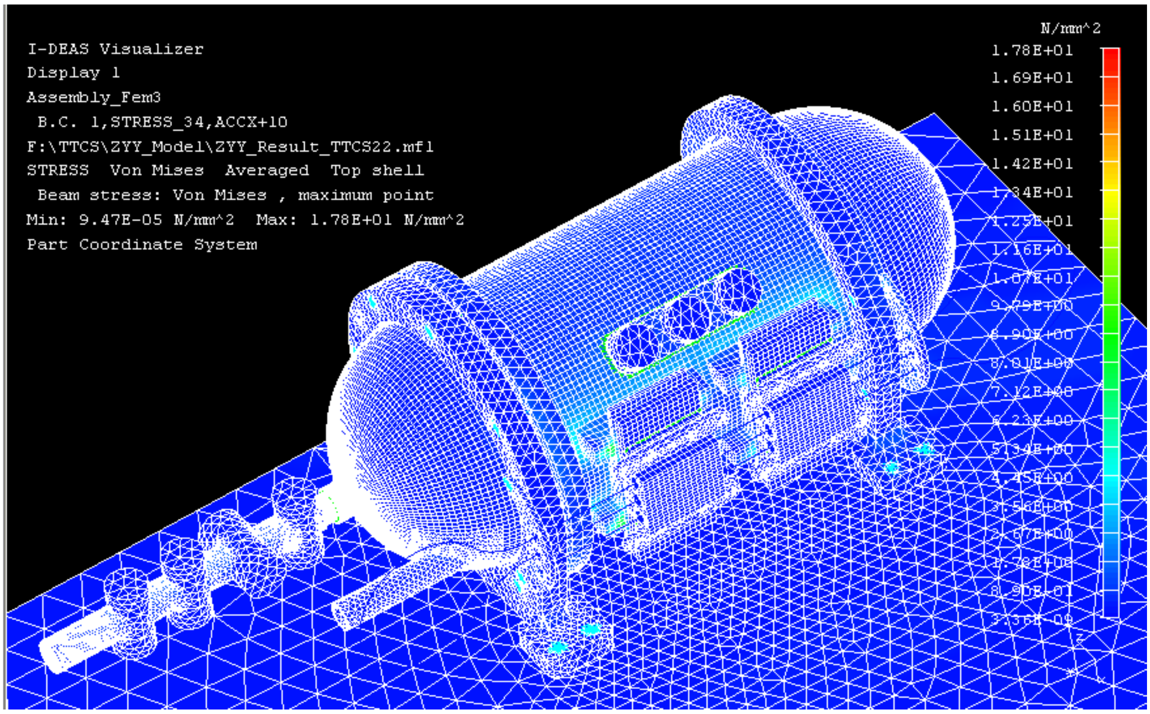


Figure 5-9 Static Analysis: Stress: Acceleration in X direction 10g

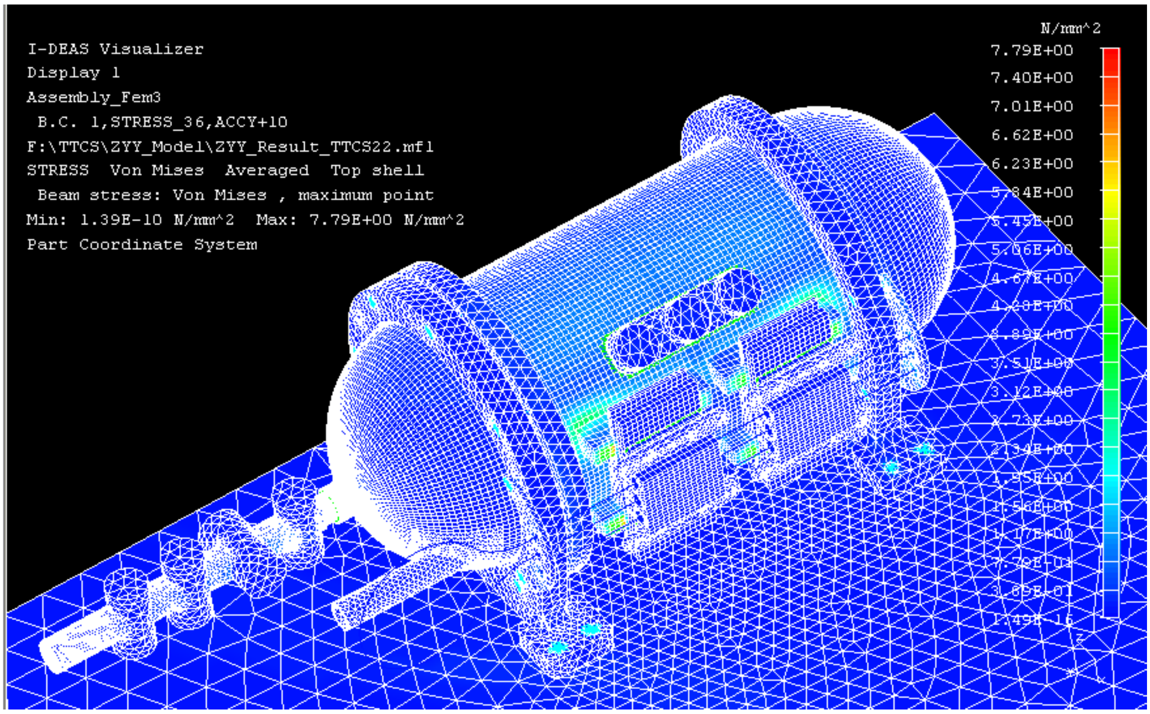


Figure 5-10 Static Analysis: Stress: Acceleration in Y direction 10g

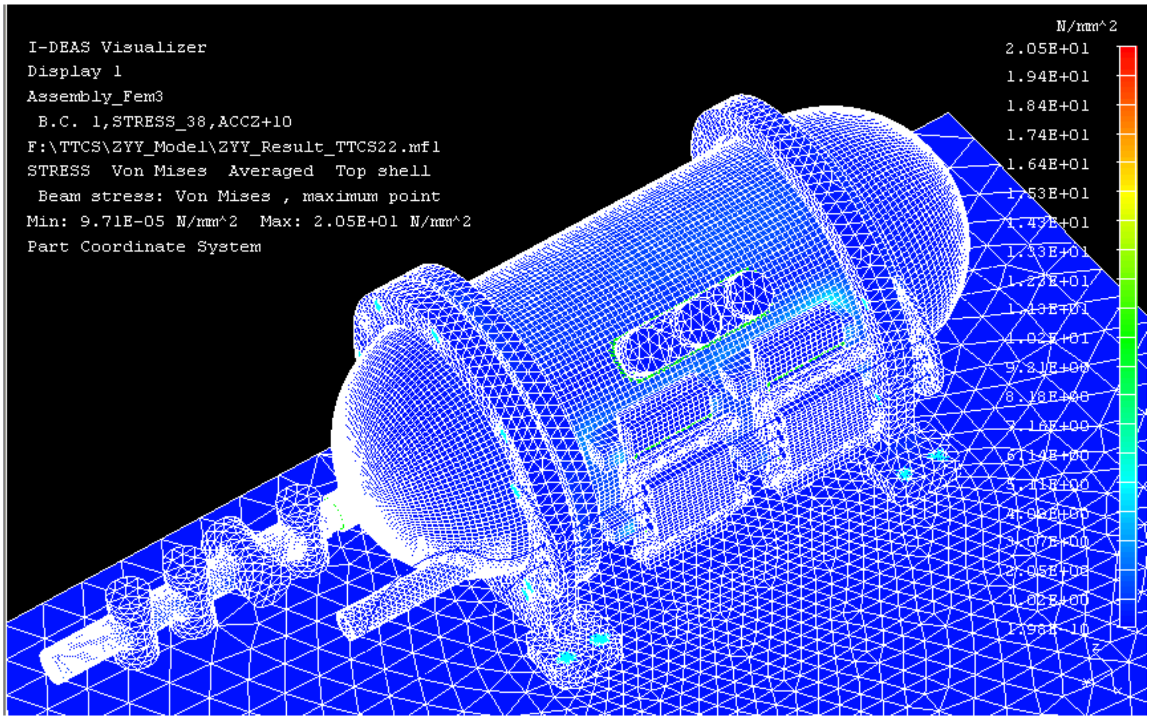


Figure 5-11 Static Analysis: Stress: Acceleration in Z direction 10g

5.1.4 Displacement under 160&57 Bar cases.

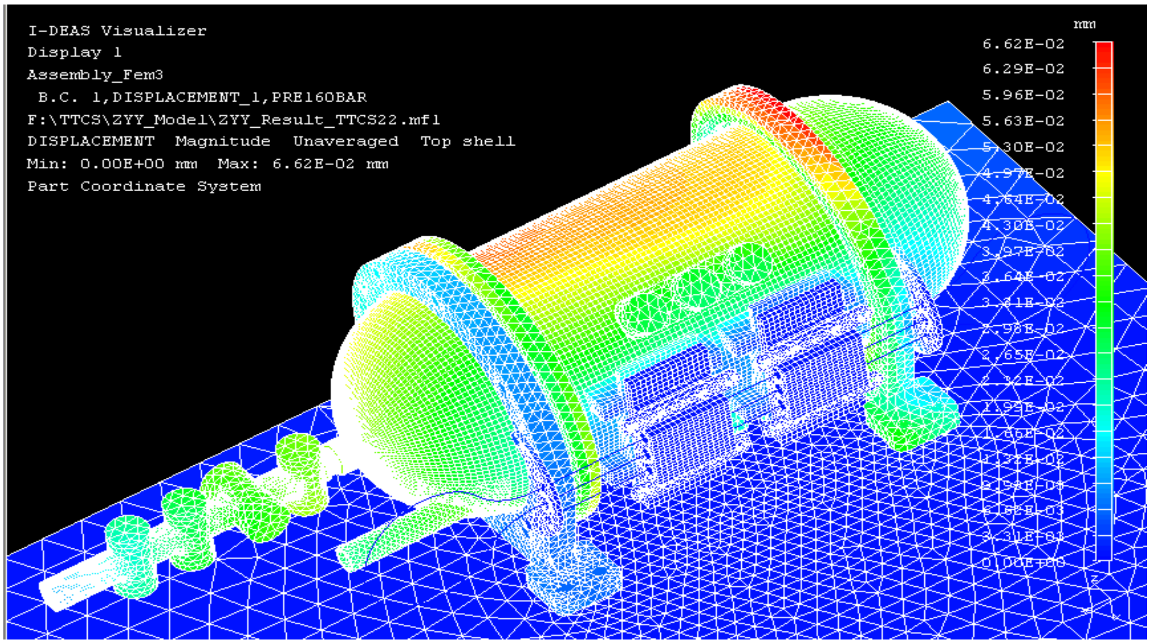


Figure 5-12 Static Analysis: Displacement: 160Bar&57Bar

5.1.5 Displacement under Six accelerations cases.

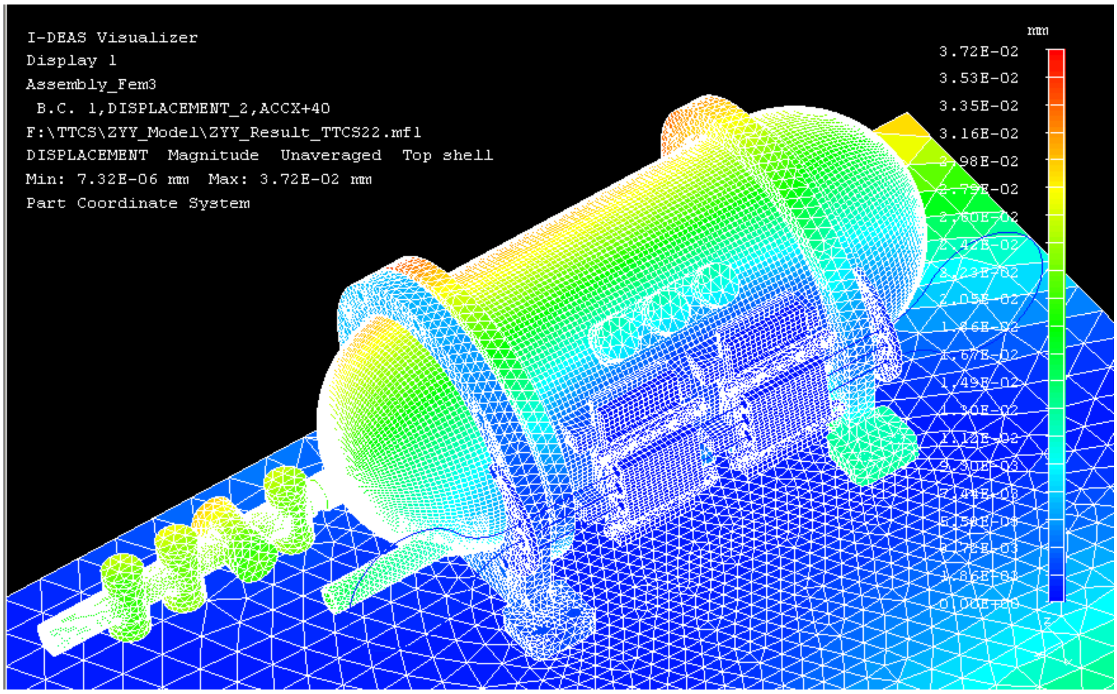


Figure 5-13 Static Analysis: Displacement: Acceleration in X direction 40g

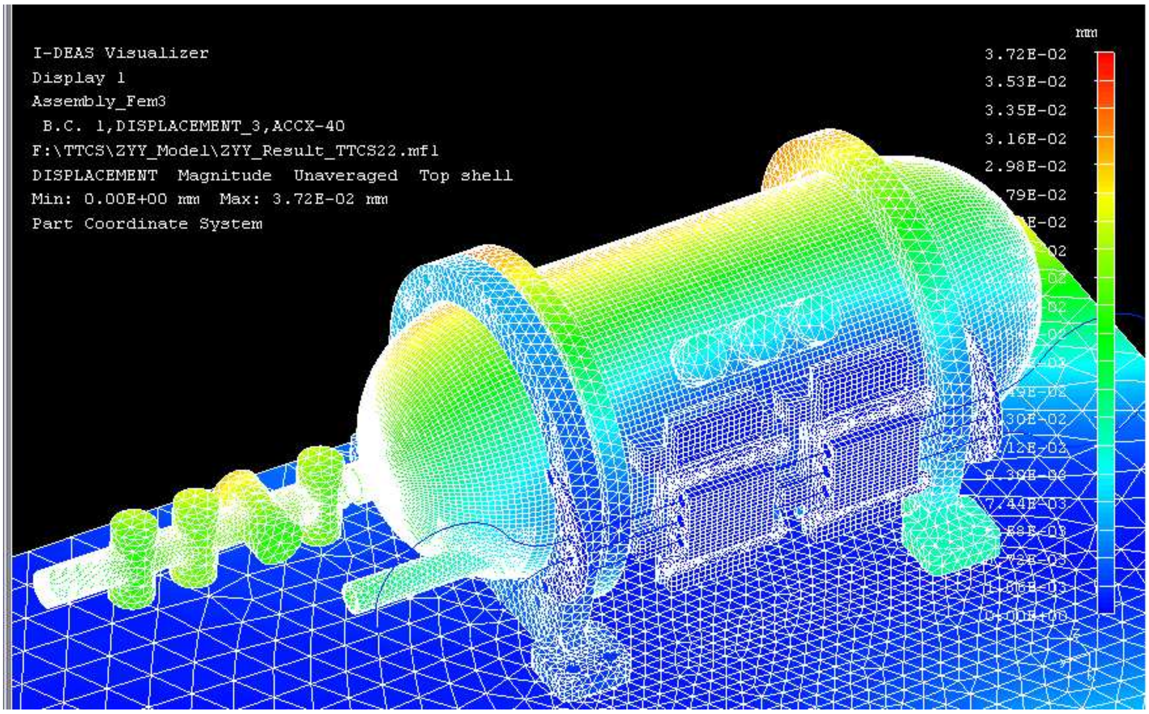


Figure 5-14 Static Analysis: Displacement: Acceleration in X direction -40g

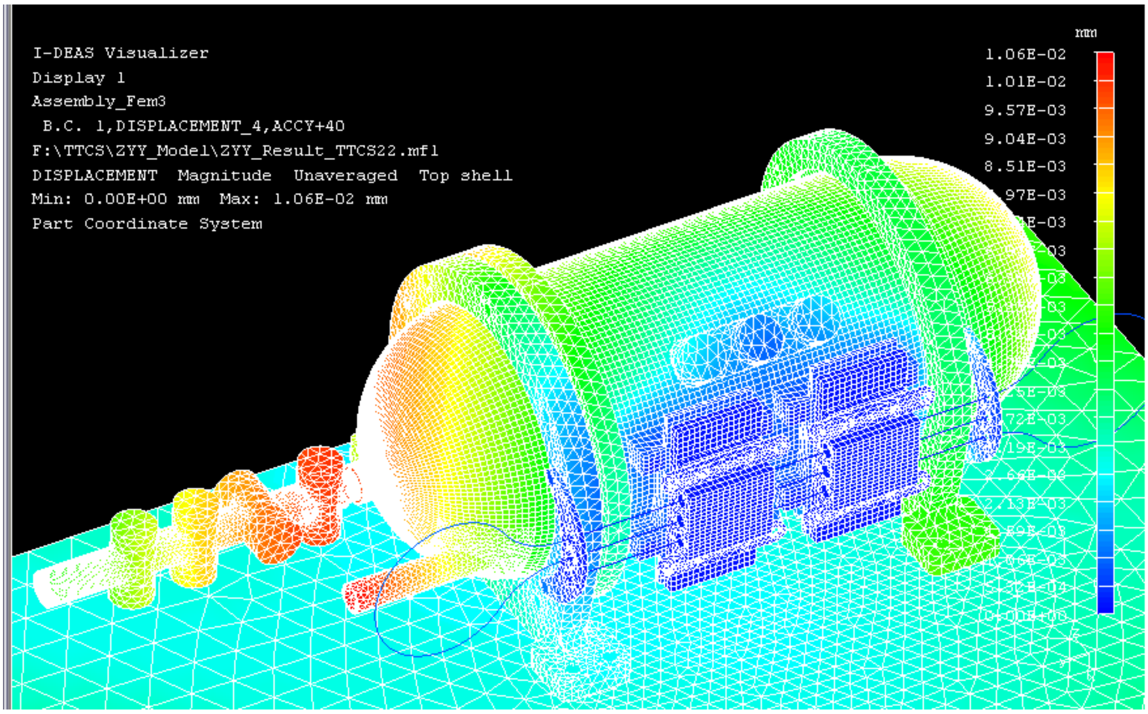


Figure 5-15 Static Analysis: Displacement: Acceleration in Y direction 40g

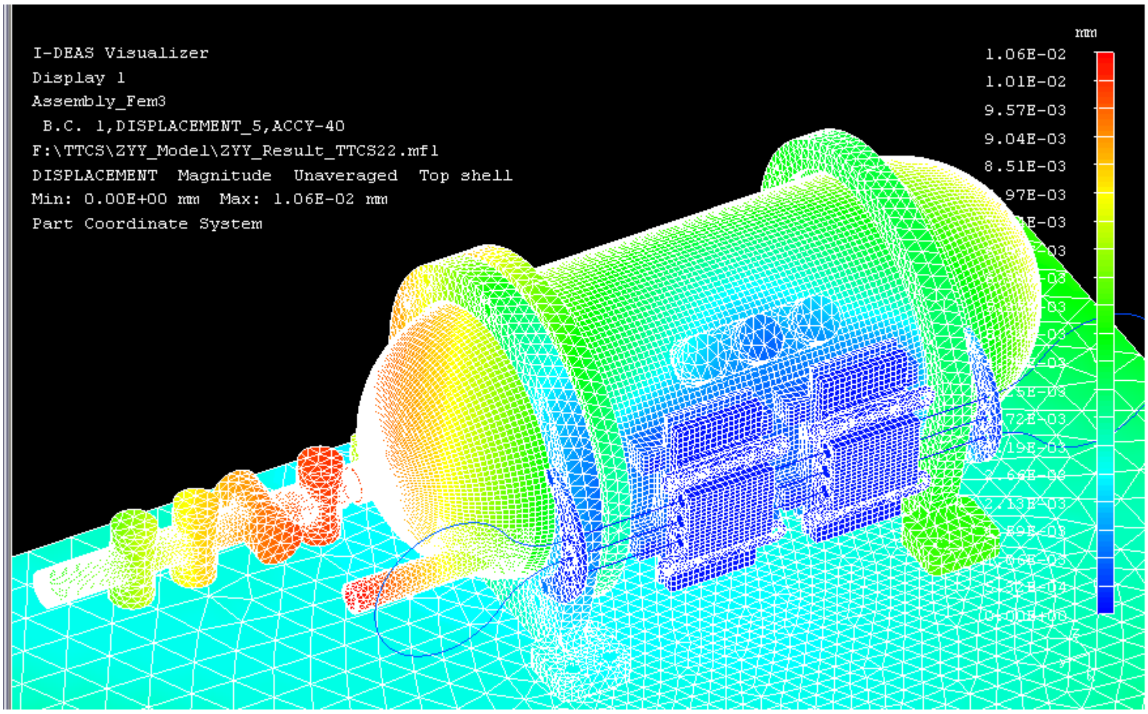


Figure 5-16 Static Analysis: Displacement: Acceleration in -Y direction 40g

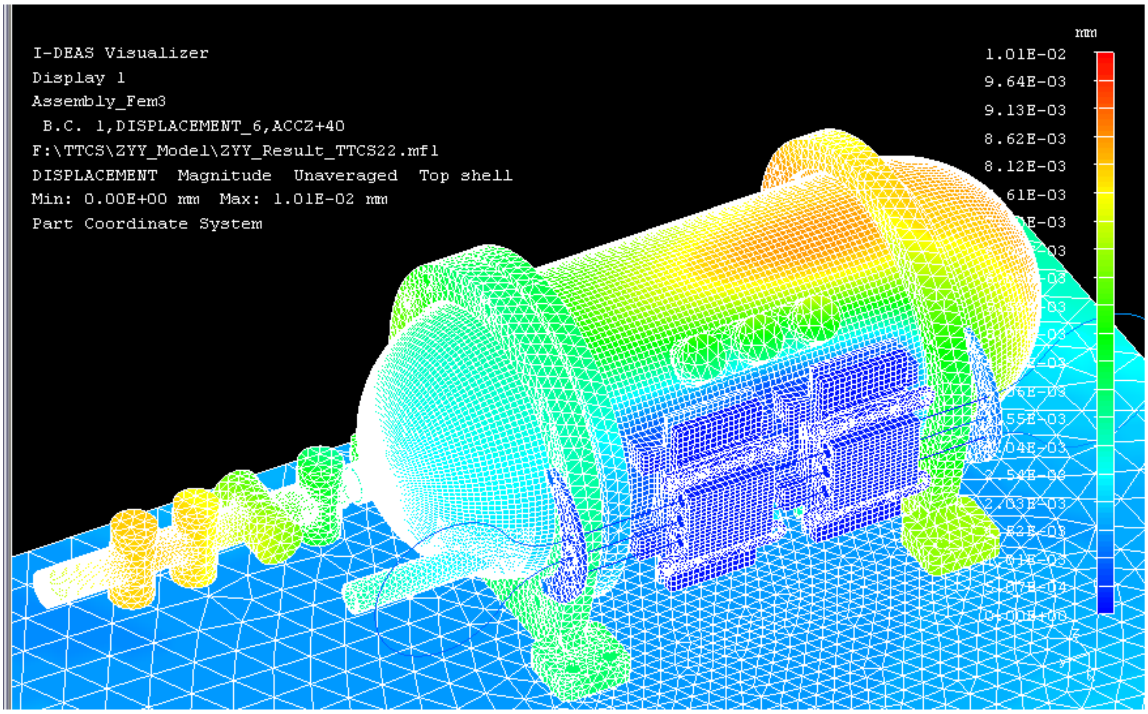


Figure 5-17 Static Analysis: Displacement: Acceleration in Z direction 40g

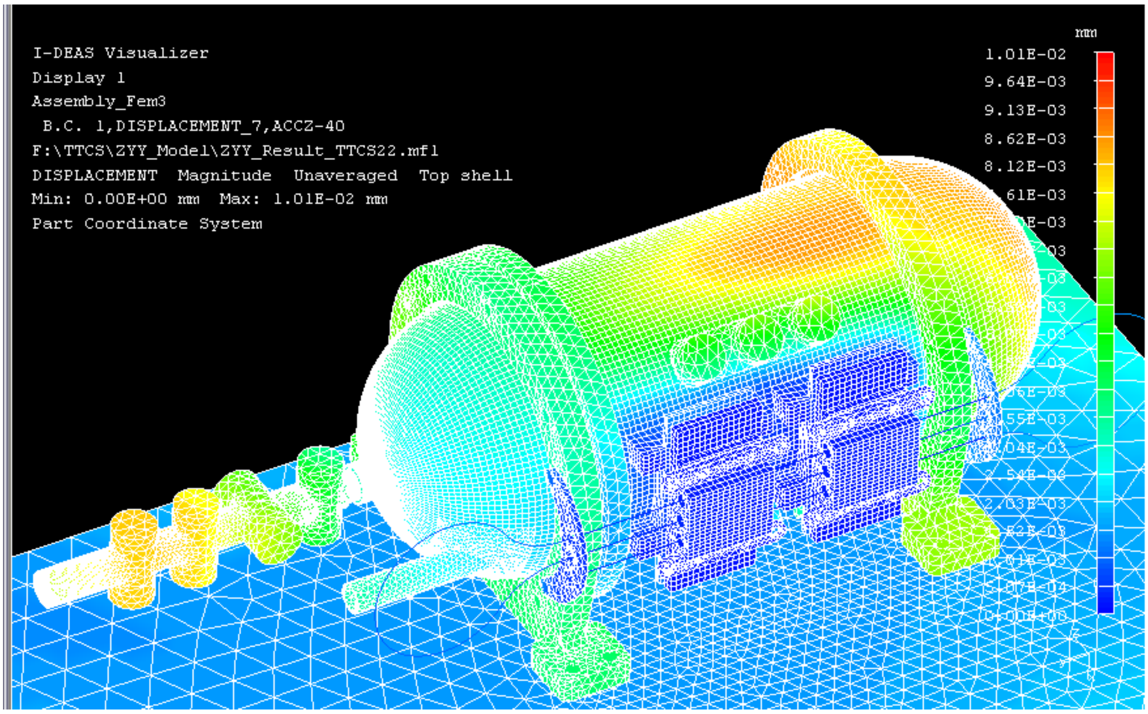


Figure 5-18 Static Analysis: Displacement: Acceleration in -Z direction 40g

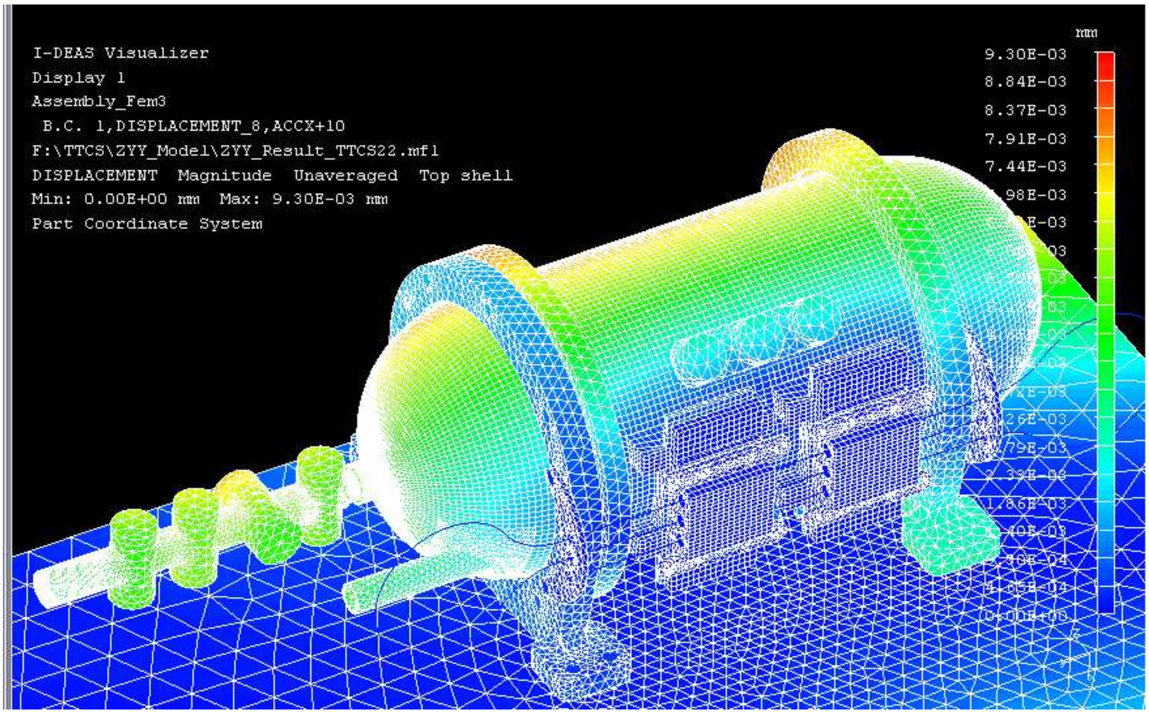


Figure 5-19 Static Analysis: Displacement: Acceleration in X direction 10g

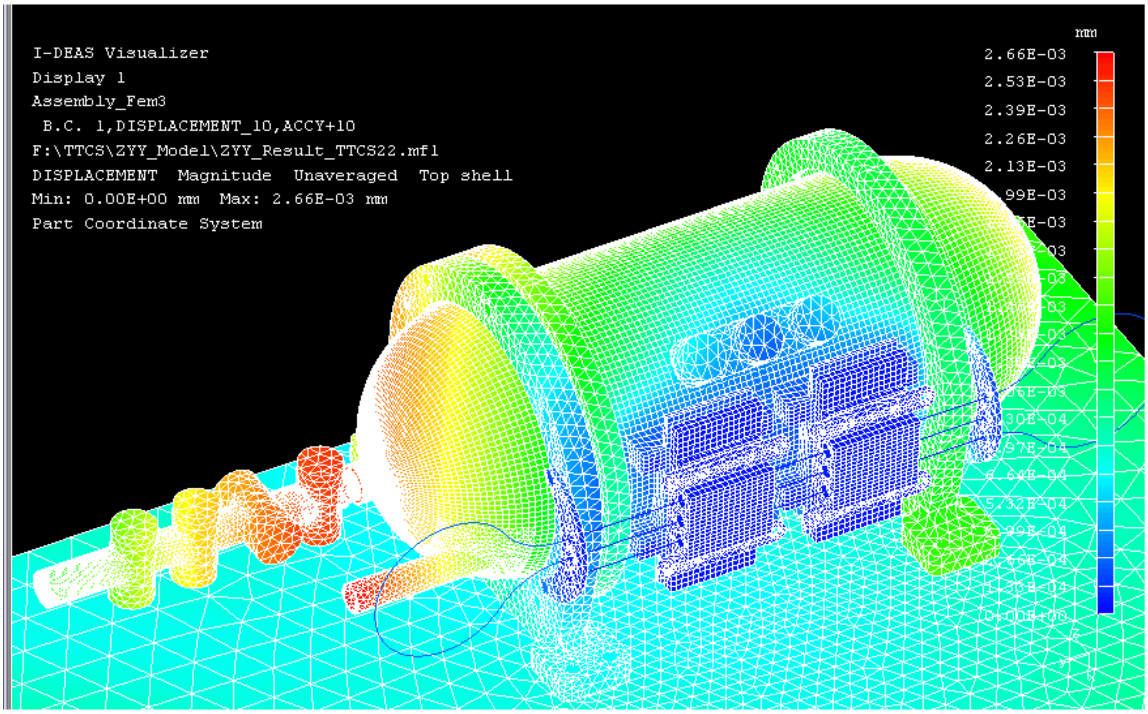


Figure 5-20 Static Analysis: Displacement: Acceleration in Y direction 10g

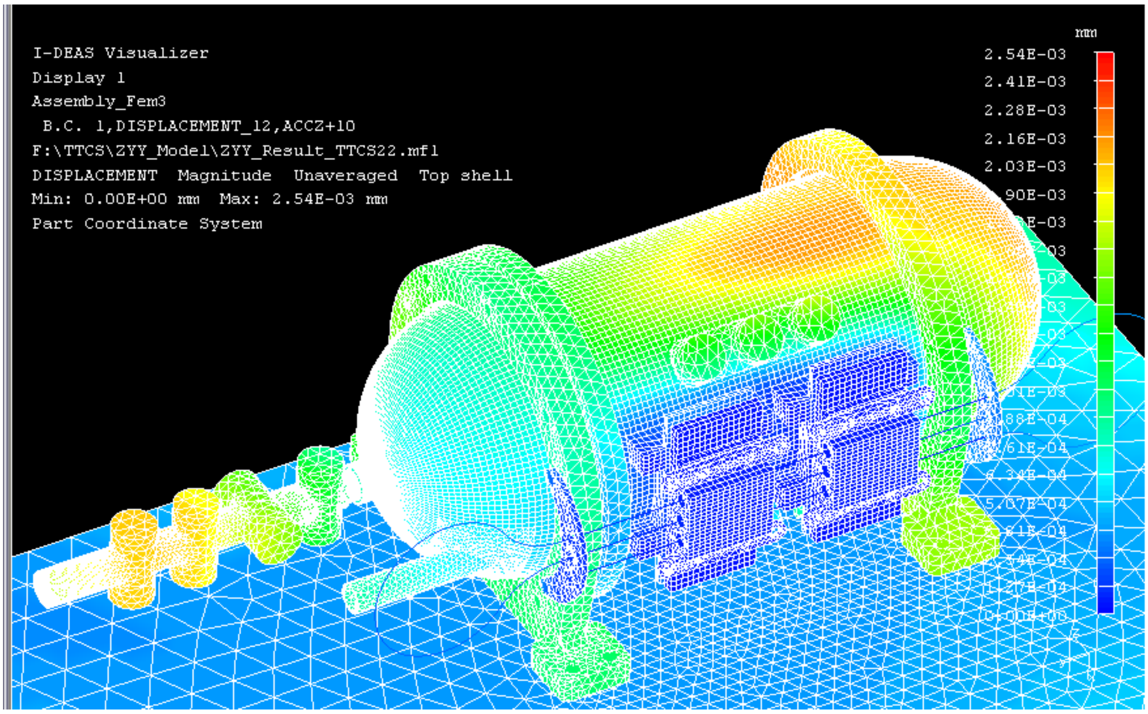


Figure 5-21 Static Analysis: Displacement: Acceleration in Z direction 10g

5.1.6 Load Combination: Pressure and Six acceleration cases.

Explanations:

P: Present Pressure load

X40: present Acceleration X 40g

X_40: present Acceleration X -40g

Y40: present Acceleration Y 40g

Y_40: present Acceleration Y -40g

Z40: present Acceleration Z 40g

Z_40: present Acceleration Z -40g

X10: present Acceleration X 10g

X_10: present Acceleration X -10g

Y10: present Acceleration Y 10g

Y_10: present Acceleration Y -10g

Z10: present Acceleration Z 10g

Z_10: present Acceleration Z -10g

P+X10+Y40+Z10: present Pressure+ Acceleration X 10g+ Acceleration Y 40g+ Acceleration Z 10g

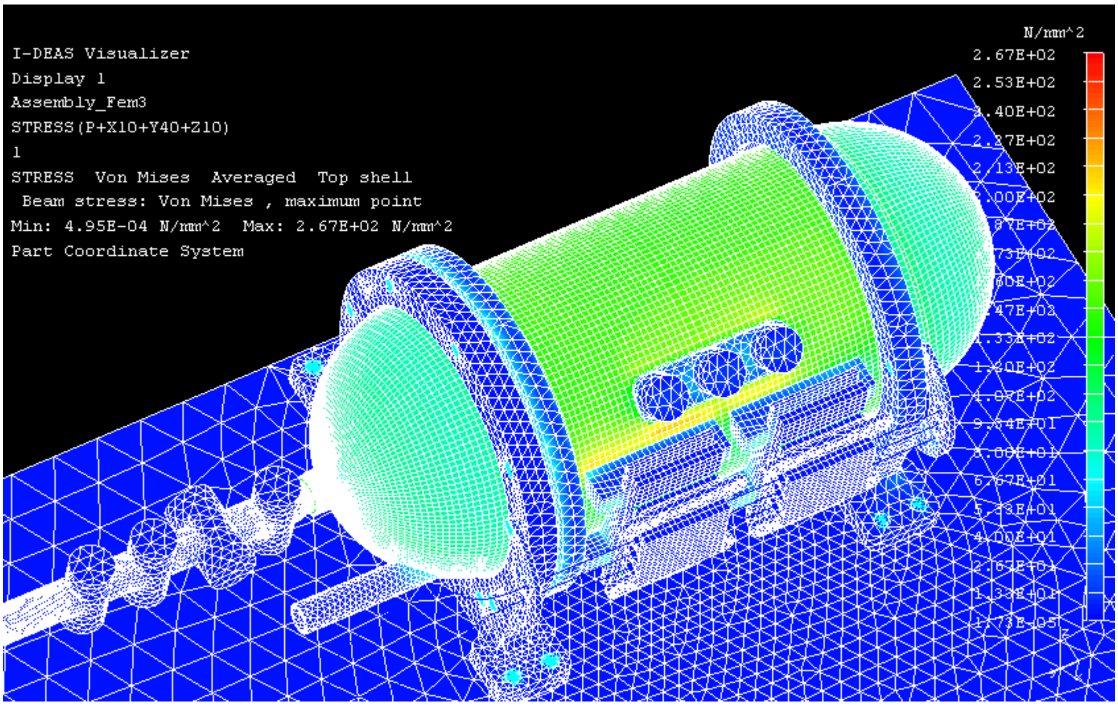


Figure 5-22 Static Analysis: Total FEM Model Stress: P+X10+Y40+Z10

Note: In Fig 5-22, the max. stress is 267Mpa and location is on connection between liquid outlet and accumulator. By analysis, the stress concentration is caused by a very small edge which is not rounded. In actual manufacturing, rounding is there. The pressure test has been performed and no failure appeared. Therefore, the maximum stress location due to the calculation is ignored. Actual maximum stress on accumulator should be where peltier copper saddle welded to accumulator.

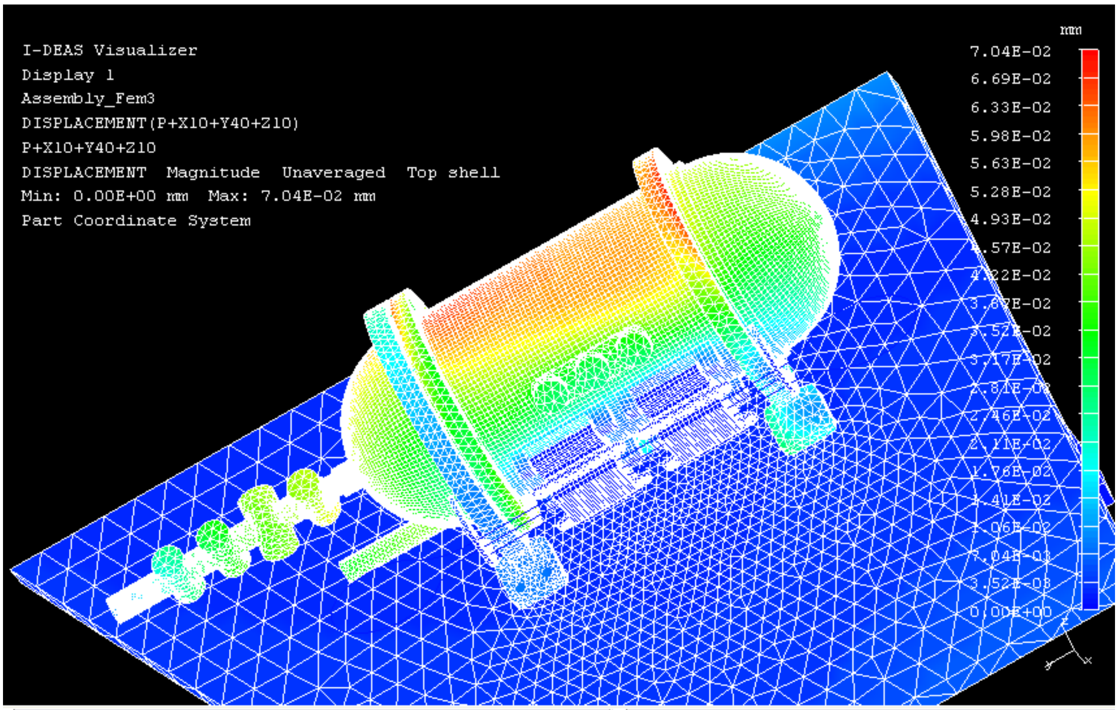


Figure 5-23 Static Analysis : Total FEM Model Displacement: P+X10+Y40+Z10

5.1.7 Result: Load Combination of Pressure and Six acceleration cases.

Table 5-2 Accumulator Stresses, Displacements and Margin of Safety

Loads Cases				Accumulator (Fsy=1.5 FSult=2.5) Material: 316Ln				
Load Case	Acceleration (g)			Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
	x	y	z	Von Mises	Max Principal		Yield	Ultimate
1	10	40	10	325.5	585.0	0.0650	0.03	0.11
2	40	10	10	321.0	580.0	0.0834	0.04	0.12
3	10	10	40	325.5	587.5	0.0654	0.03	0.11

4	-10	40	-10	324.0	587.5	0.0643	0.03	0.11
5	10	-40	-10	321.0	582.5	0.0658	0.04	0.12
6	-10	-40	10	324.0	587.5	0.0552	0.03	0.11

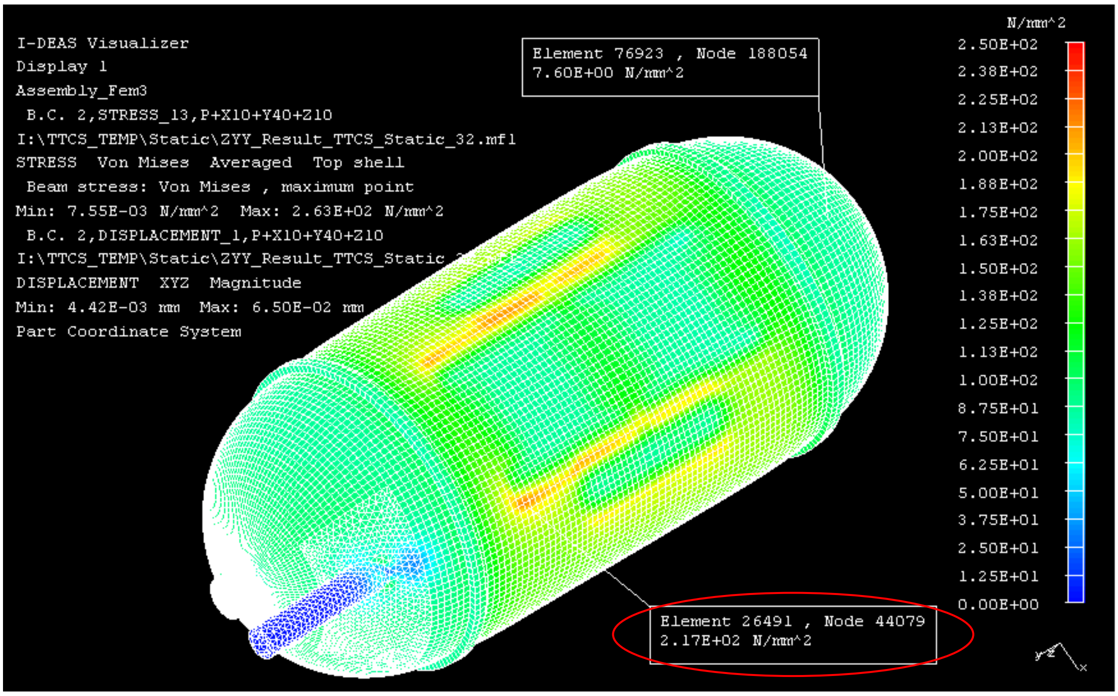


Figure 5-24 Static Analysis: Accumulator Stress: P+X10+Y40+Z10

Table 5-3 Peltier Copper Saddle Stresses, Displacements and Margin of Safety

Loads Cases				Peltier Copper Saddle (Fsy=1.25 FSult=2) Material :Copper				
Load	Acceleration (g)			Max Stress [N/mm2]		Displacement	Margin of Safety	
Case	x	y	z	Von Mises	Max Principal	(mm)	Yield	Ultimate

1	10	40	10	76.9	141.6	0.0188	0.04	0.55
2	40	10	10	65.0	115.4	0.0218	0.23	0.91
3	10	10	40	64.5	115.2	0.0199	0.24	0.91
4	-10	40	-10	72.5	157.6	0.0179	0.10	0.4
5	10	-40	-10	61.9	110.8	0.0199	0.29	0.99
6	-10	-40	10	61.8	111.0	0.0186	0.30	0.98

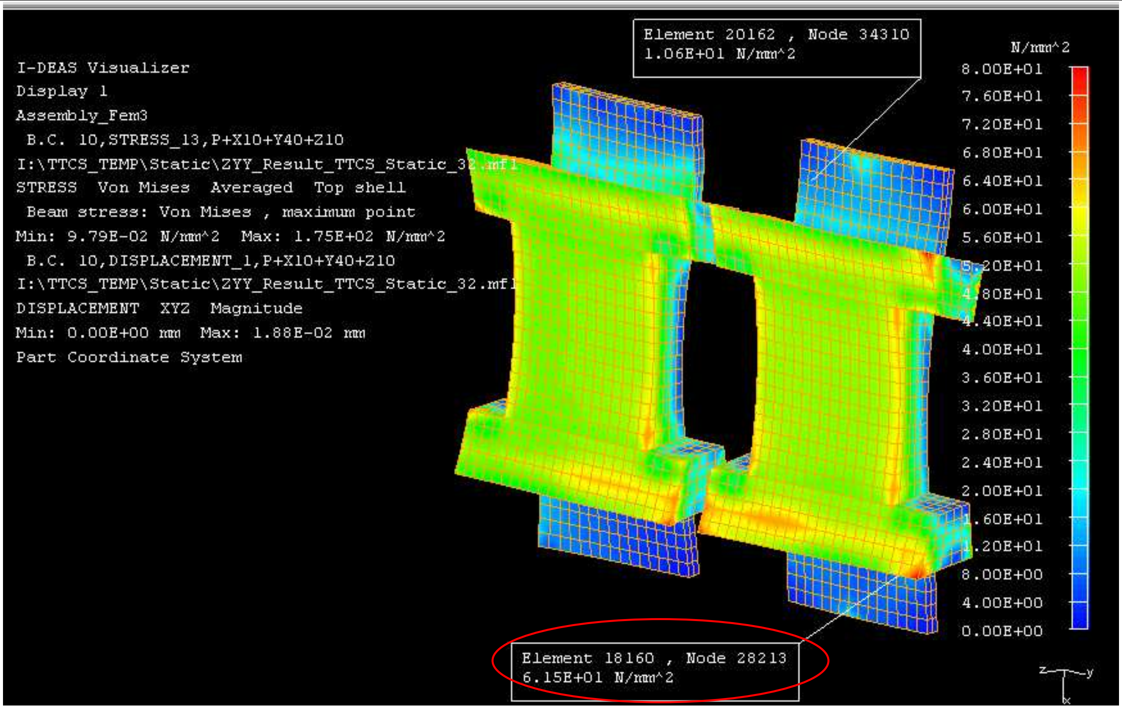


Figure 5-25 Static Analysis: Pelitier Copper Saddle Stress: P+X10+Y40+Z10

Table 5-4 **Clamp Collar&Wedge** Stresses, Displacements and Margin of Safety

Loads Cases	Fixed Bracket & Clamp Collar&Wedge (Fsy=1.25 FSult=2) Material :316L

Load Case	Acceleration (g) x	y	z	Max Stress [N/mm2] Von Mises	Max Principal	Displacement (mm)	Margin of Safety Yield	Ultimate
1	10	40	10	113.6	176.6	0.0636	1.11	2.11
2	40	10	10	114.5	177.0	0.0837	1.10	2.11
3	10	10	40	113.8	176.4	0.0647	1.11	2.12
4	-10	40	-10	113.9	176.4	0.0633	1.11	2.12
5	10	-40	-10	114.1	176.4	0.0591	1.10	2.12
6	-10	-40	10	114.1	176.0	0.0484	1.10	2.13

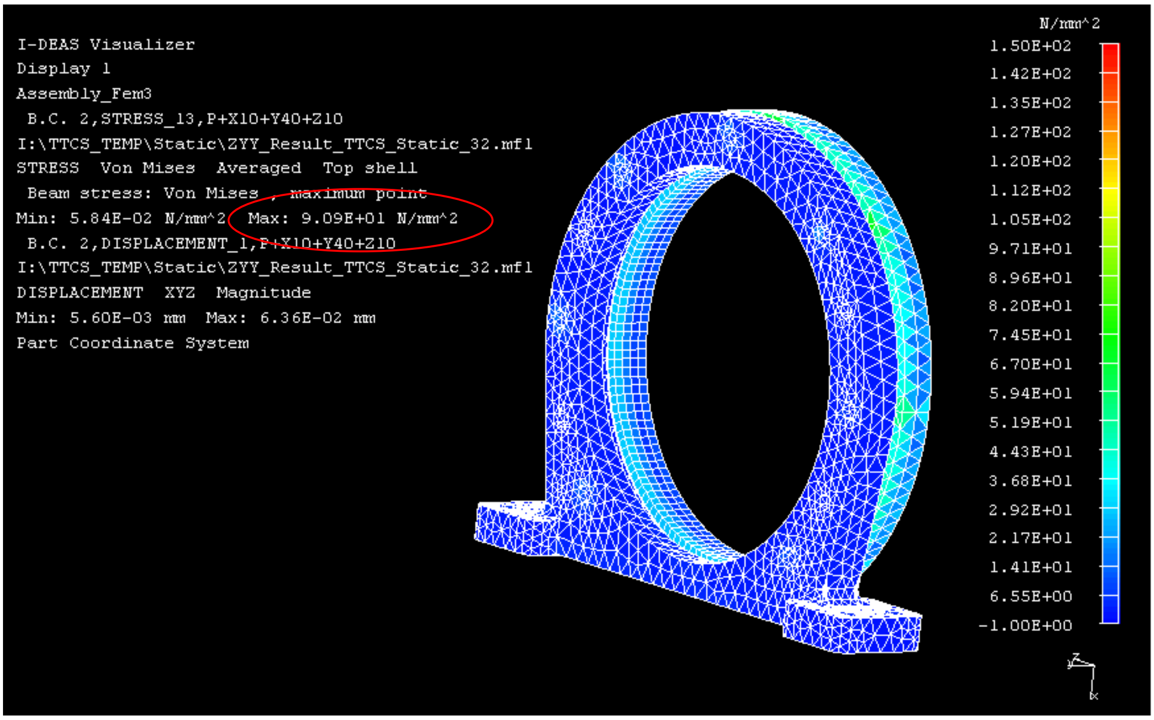


Figure 5-26 Static Analysis: Fixed Bracket Assembly Stress: P+X10+Y40+Z10

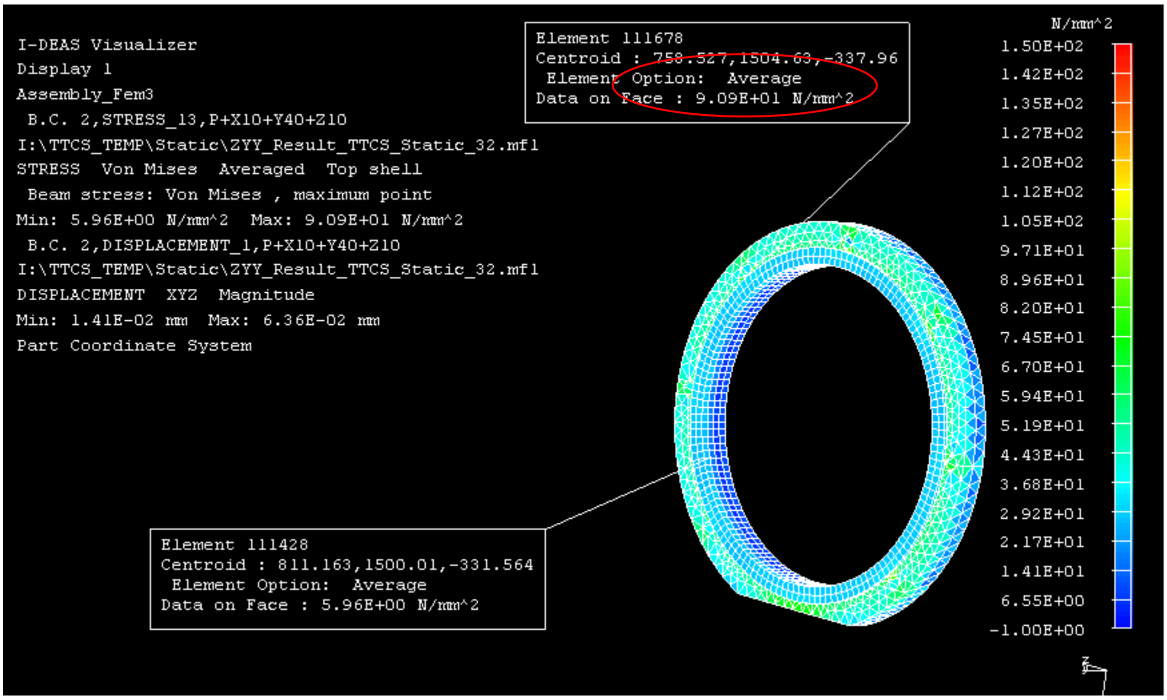


Figure 5-27 Static Analysis: Fixed Bracket Clamp collar&Wedge Stress: P+X10+Y40+Z10

Table 5-5 **Sliding Bracket** Stresses, Displacements and Margin of Safety

Loads Cases				Sliding Bracket (Fsy=1.25 FSult=2) Material :Al 7075				
Load Case	Acceleration (g)			Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
	x	y	z	Von Mises	Max Principal		Yield	Ultimate
1	10	40	10	78.4	64.6	0.0928	4.01	6.26
2	40	10	10	66.8	102.8	0.0853	4.88	3.56
3	10	10	40	68.3	63.6	0.0693	4.75	6.37

4	-10	40	-10	68.3	62.4	0.0606	4.75	6.51
5	10	-40	-10	61.4	63.4	0.0729	5.40	6.39
6	-10	-40	10	62.5	62.2	0.0648	5.29	6.54

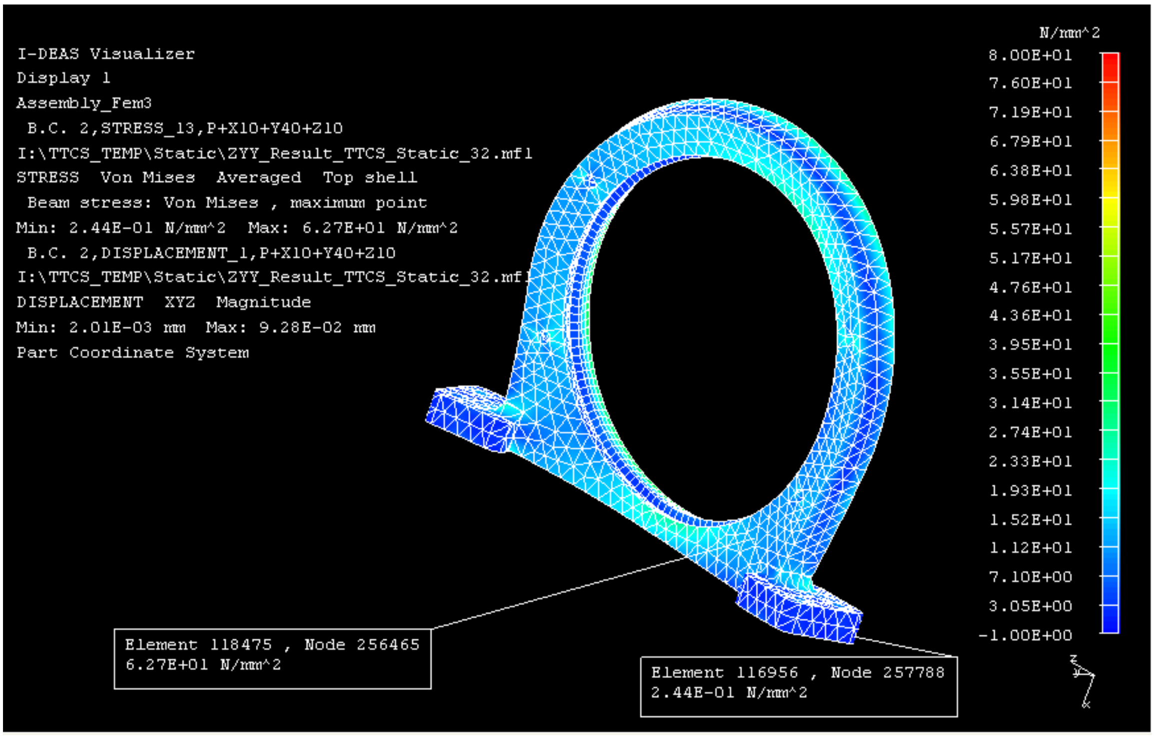


Figure 5-28 Static Analysis: Sliding Bracket Stress: P+X10+Y40+Z10

Table 5-6 **Heat Pipe** Stresses, Displacements and Margin of Safety under different load cases

Loads Cases		Heat Pipe ($FS_y = 1.5 \ \ FS_{ult} = 4$) Material :316L		
Load	Acceleration (g)	Max Stress [N/mm2]	Displacement	Margin of Safety

Case	x	y	z	Von Mises	Max Principal	(mm)	Yield	Ultimate
1	10	40	10	96.0	151.6	0.0541	1.50	2.63
2	40	10	10	117.3	158.8	0.0636	1.05	2.46
3	10	10	40	96.0	152.4	0.0475	1.50	2.61
4	-10	40	-10	93.8	144.8	0.0487	1.56	2.80
5	10	-40	-10	95.9	136.0	0.0446	1.50	3.04
6	-10	-40	10	90.9	134.8	0.0352	1.64	3.08

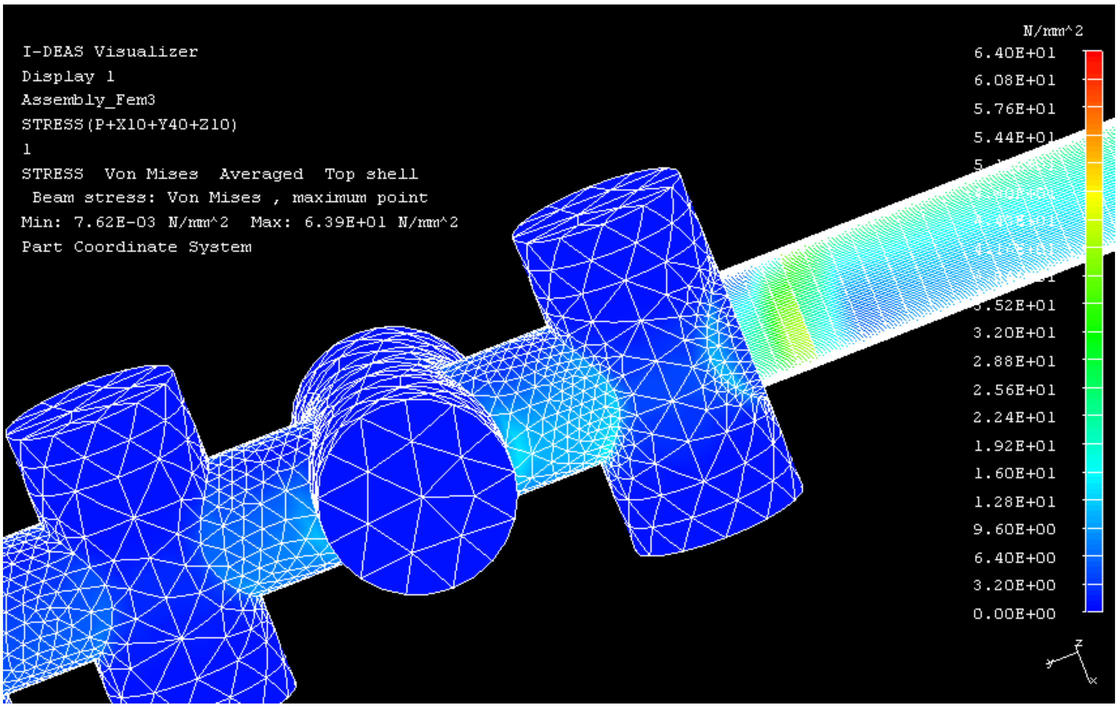


Figure 5-29 Static Analysis: Heat Pipe Assembly Stress: P+X10+Y40+Z10

Table 5-7 **Peltier Fixed** Stresses, Displacements and Margin of Safety

Loads Cases	Peltier Fixed ($FS_y = 1.25 \quad FS_{ult} = 2$)

				Material :316L				
Load Case	Acceleration (g)			Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
	x	y	z	Von Mises	Max Principal		Yield	Ultimate
1	10	40	10	68.4	144.6	0.0319	2.51	2.80
2	40	10	10	65.3	147.0	0.0310	2.68	2.74
3	10	10	40	67.3	151.8	0.0295	2.57	2.62
4	-10	40	-10	67.5	148.4	0.0313	2.56	2.71
5	10	-40	-10	74.8	165.6	0.0270	2.21	2.32
6	-10	-40	10	78.1	168.8	0.0273	2.07	2.26

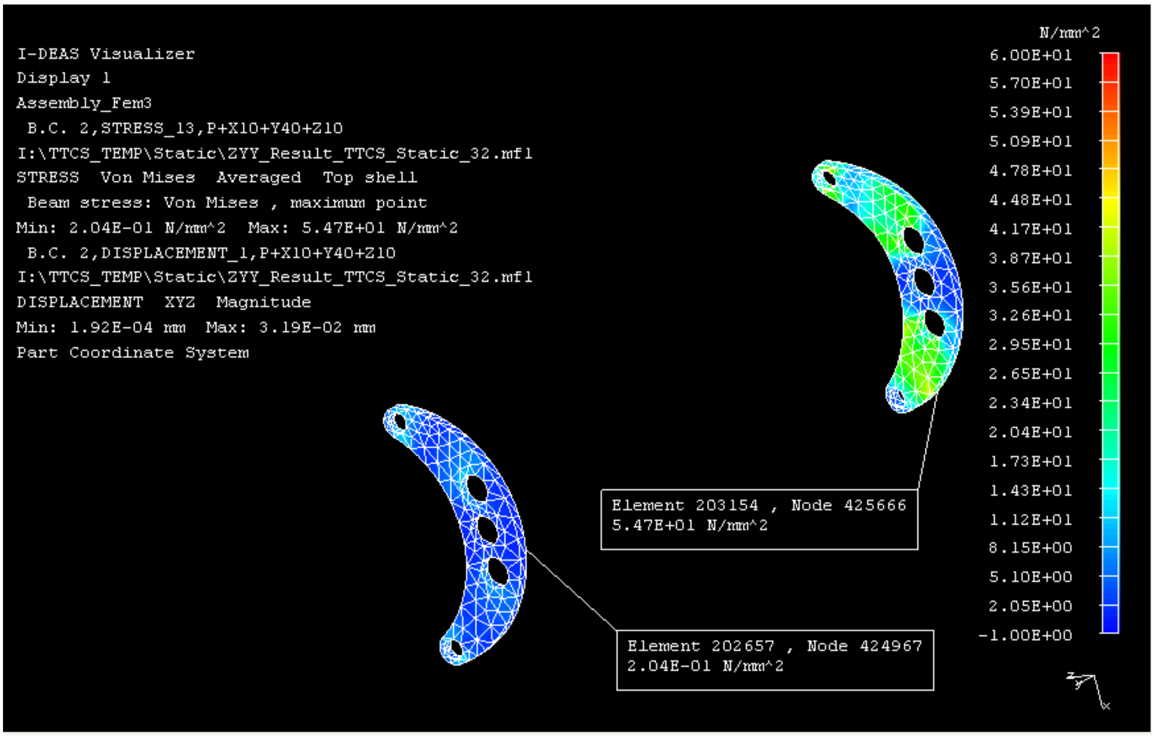


Figure 5-30 Static Analysis: Peltier Fixed Stress: P+X10+Y40+Z10

Table 5-8 **Peltier Heat Exchanger** Stresses, Displacements and MoS

Loads Cases				Peltier Heat Exchanger ($FS_y = 1.25$ $FS_{ult} = 2$) Material :Copper				
Load Case	Acceleration (g)			Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
	x	y	z	Von Mises	Max Principal		Yield	Ultimate
1	10	40	10	2.32	5.20	0.000231	33.41	41.31
2	40	10	10	5.47	8.94	0.000407	13.61	23.61
3	10	10	40	3.08	4.64	0.000285	24.91	46.41
4	-10	40	-10	2.18	2.56	0.000238	35.57	84.94
5	10	-40	-10	5.22	3.30	0.000294	14.31	65.67
6	-10	-40	10	3.38	2.44	0.000207	22.62	89.16

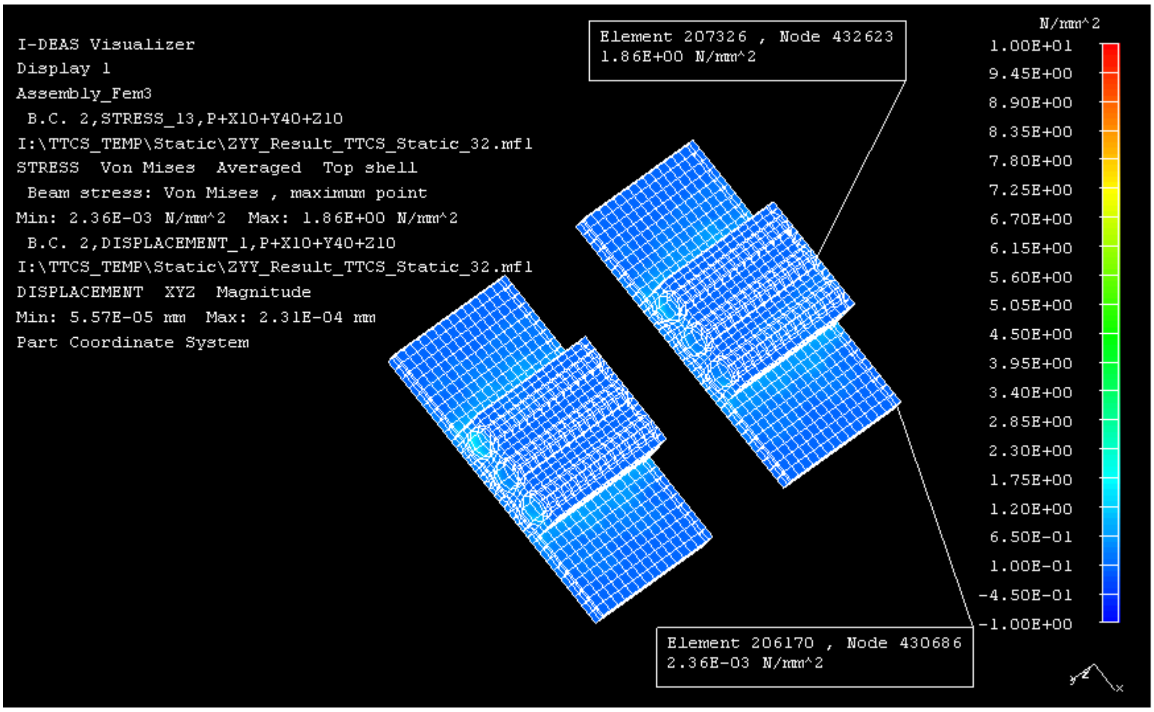


Figure 5-31 Static Analysis: Peltier Heat Exchanger Stress: P+X10+Y40+Z10

Table 5-9 **TS &Peltier HT press & Spring Support** Stresses, Displacements and Mofs

Loads Cases				TS &Peltier heat exchanger press &Spring Support Material :316L($FS_y = 1.25$ $FS_{ult} = 2$)				
Load Case	Acceleration (g)			Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
	x	y	z	Von Mises	Max Principal		Yield	Ultimate
1	10	40	10	141.25	248	0.0416	0.70	1.22
2	40	10	10	148.75	258	0.0494	0.61	1.13
3	10	10	40	138.75	238	0.0464	0.73	1.31
4	-10	40	-10	141.25	244	0.0371	0.70	1.25

5	10	-40	-10	141.25	244	0.0386	0.70	1.25
6	-10	-40	10	135.01	232	0.0367	0.78	1.37

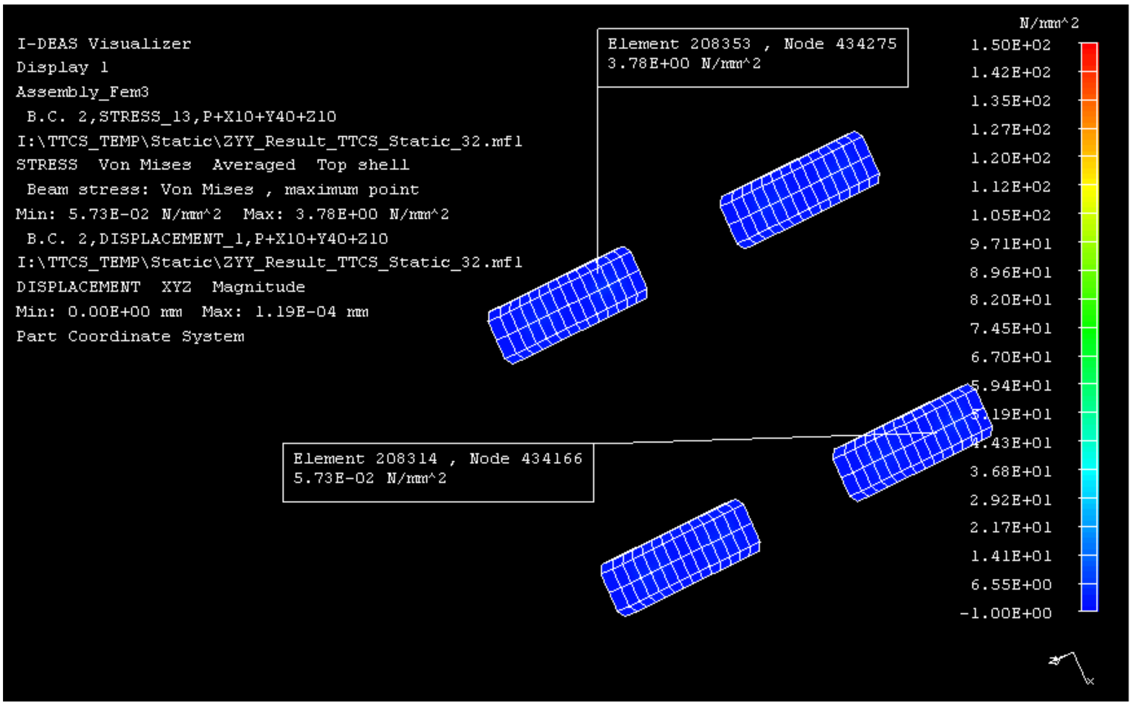


Figure 5-32 Static Analysis: Peltier heat exchanger Spring Support Stress: P+X10+Y40+Z10

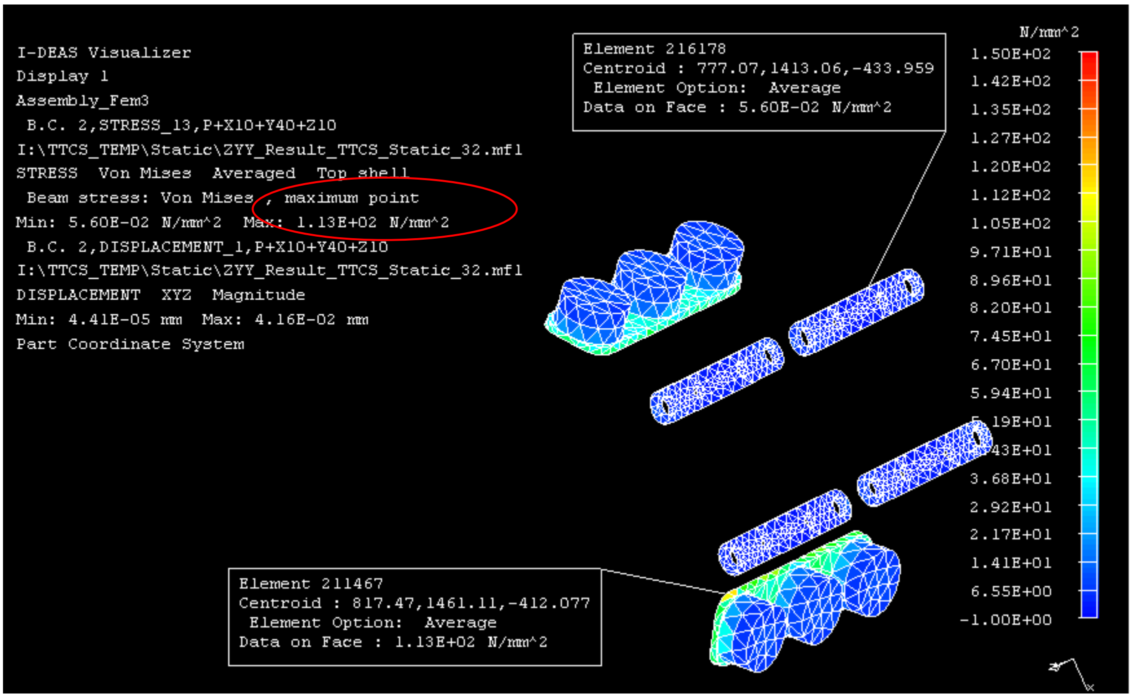


Figure 5-33 Static Analysis:TS &Peltier heat exchanger press Stress: P+X10+Y40+Z10

5.1.8 Bolts Location

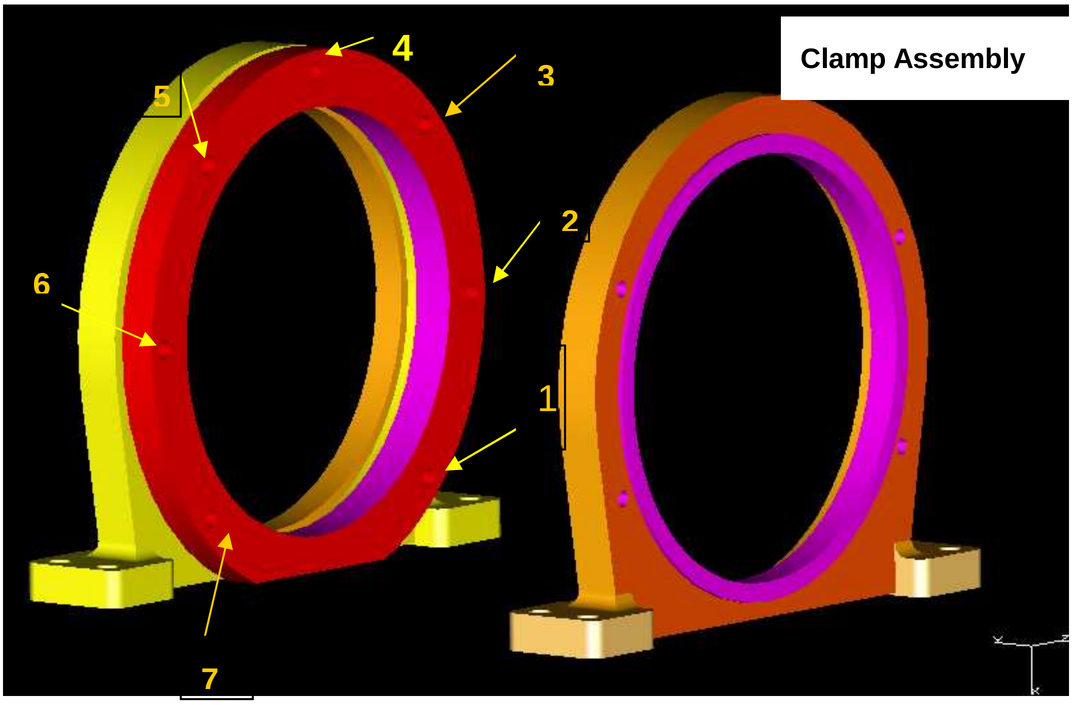


Figure 5-34 Bolts Analysis: Bolts Location (1)

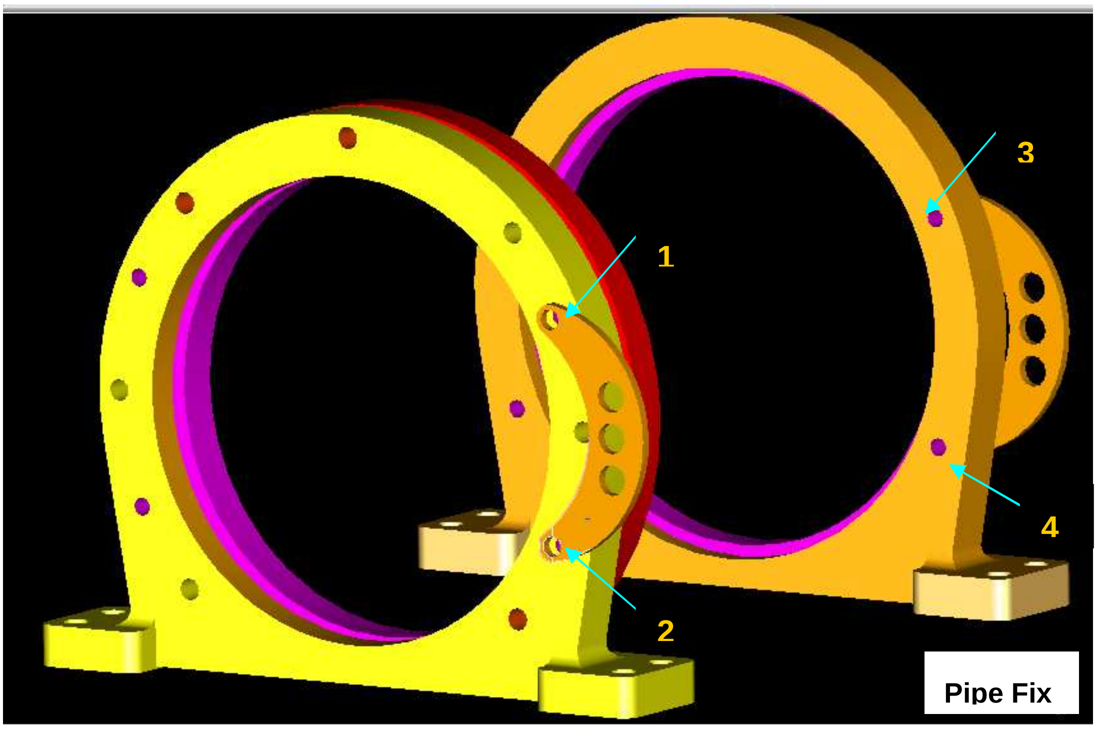


Figure 5-35 Bolts Analysis: Bolts Location (2)

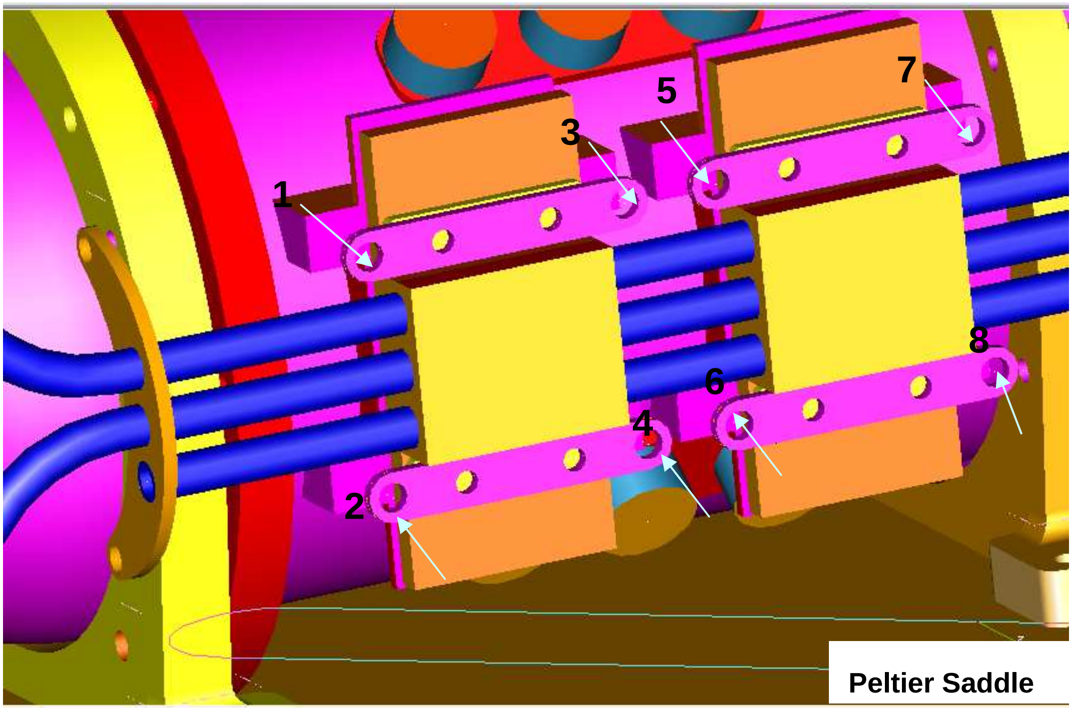


Figure 5-36 Bolts Analysis: Bolts Location (3)

Table 5-10 Accu.Bracket Clamp&Collar Bolt Element Force and MoS Calculation

(Preload:65%) 7 bolts in total

Accu.Bracket Clamp&Collar Bolt element force and MofSafety Calculation									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
1 (10.40.10)	5.61	41.5	-31.4	31.9	7.12	41.5	9.26	3.2	0.12
2 (40.10.10)	13	41.1	-33.2	35.65	7.96	41.1	9.17	3.38	0.12
3 (10.10.40)	6.11	40.8	-31.8	32.1	7.17	40.8	9.11	3.18	0.12
4 (-10.40.-10)	0.76	41.2	-29.1	29.2	6.52	41.2	9.20	3.0	0.12
5 (10.-40.-10)	6.28	39.5	-29	29.7	6.63	39.5	8.82	3.0	0.12
6 (-10.-40.10)	1.69	39.3	-28	28.1	6.27	39.3	8.77	2.9	0.12

Table 5-11 PipeFix&Clamp Bolt Element Force and MoS Calculation

(Preload: 65%)4 bolts in total

PipeFix&Clamp Bolt element force and MofSafety Calculation									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
1 (10.40.10)	4.24	7.16	-9	9.95	2.22	7.16	1.60	0	0.124
2 (40.10.10)	5.79	7.63	-7.96	9.84	2.20	7.63	1.70	0	0.124
3 (10.10.40)	4.5	6.64	-6.23	7.69	1.72	6.64	1.48	0	0.124

4 (-10.40.-10)	3.33	7.11	-10.6	11.1	2.48	7.11	1.59	0	0.124
5 (10.-40.-10)	-7.67	19.4	7.54	10.8	2.41	19.4	4.33	0	0.124
6 (-10.-40.10)	-7.82	20.3	8.31	11.4	2.54	20.3	4.53	0	0.123

Table 5-12 Press&Saddle Bolt Contraint Force and MoS Calculation

(Preload: 65%)8 bolts in total

Press&Saddle **Bolt Contraint** ***force and MofSafety Calculation***									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
1	47.9	101	170	112	25	170	37.95	0	0.107
2	55	91.9	166	107	23.88	166	37.05	0	0.108
3	46.3	93.5	172	104	23.2	172	38.4	0	0.107
4	45.6	99.7	148	109	24.3	148	33.03	0	0.108
5	-34.2	-134	-116	138	30.8	116	25.9	0	0.11
6	-38.6	-123	-106	129	28.79	106	23.66	0	0.11

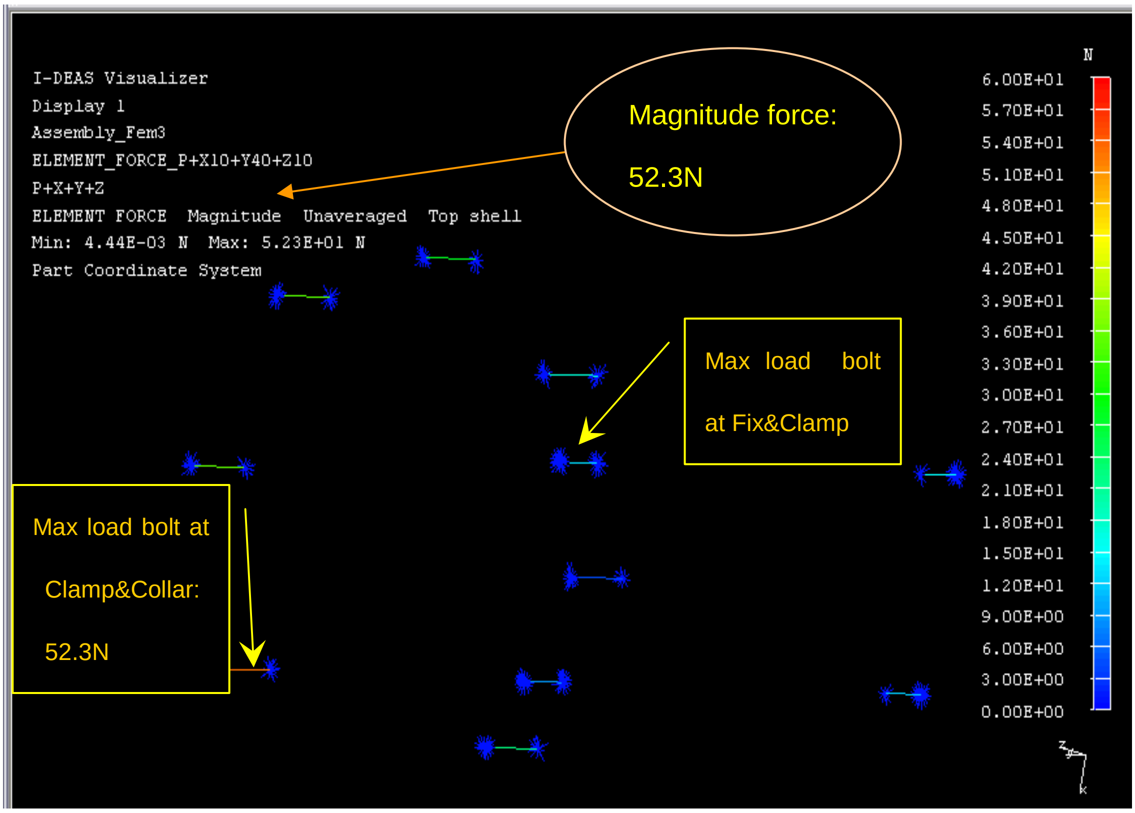


Figure 5-37 Clamp&Collar/ Fix&Clamp element magnitude force; Load case (10,40,10)g

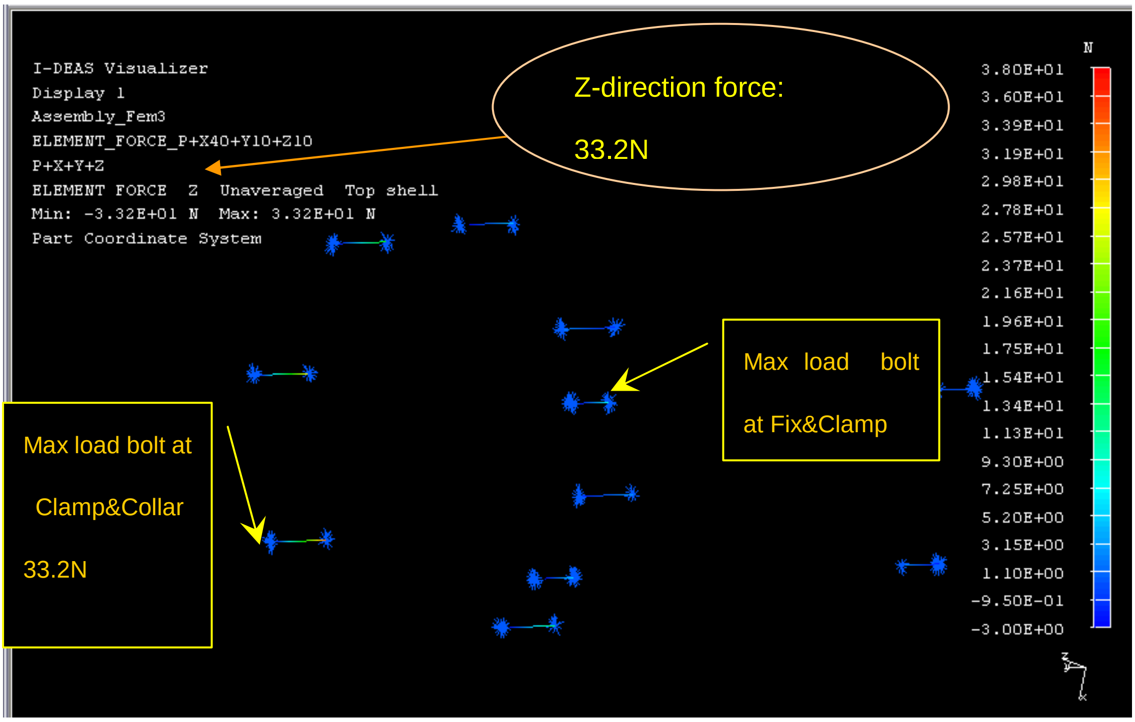


Figure 5-38 Clamp&Collar/ Fix&Clamp element Z-Direction forces ; Load case (40,10,10)g

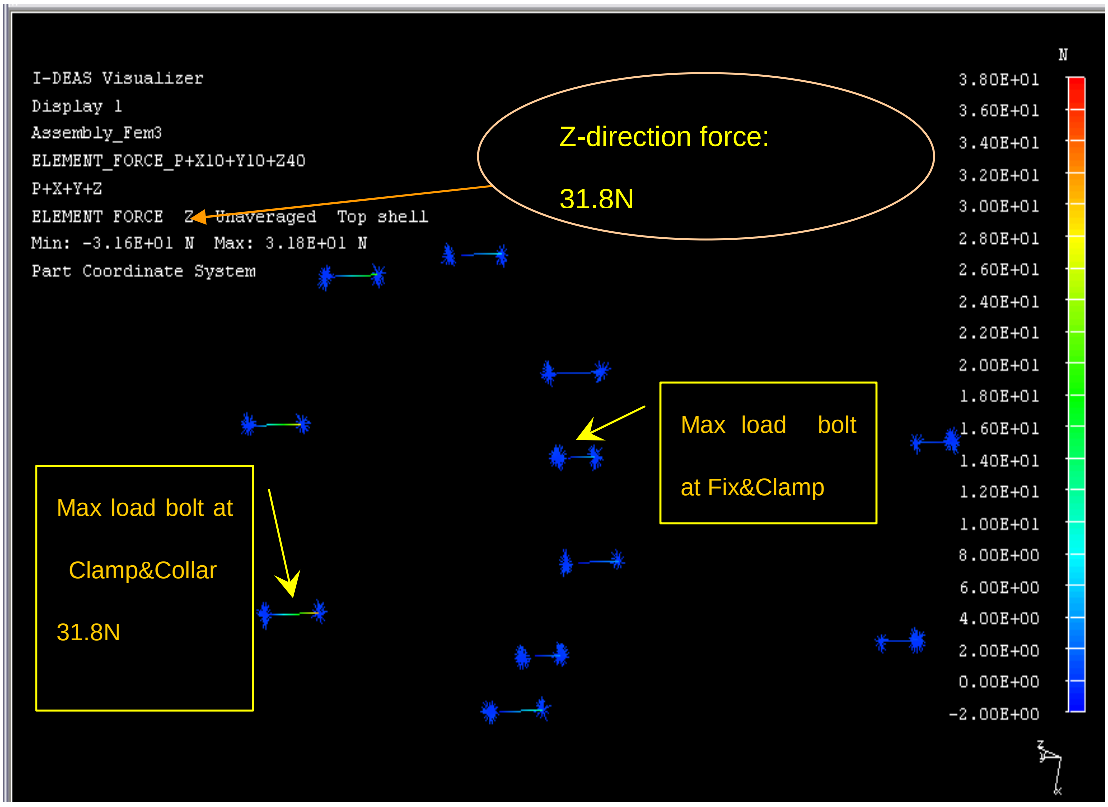


Figure 5-39 Clamp&Collar/ Fix&Clamp element Z-Direction forces; Load case (10,10,40)g

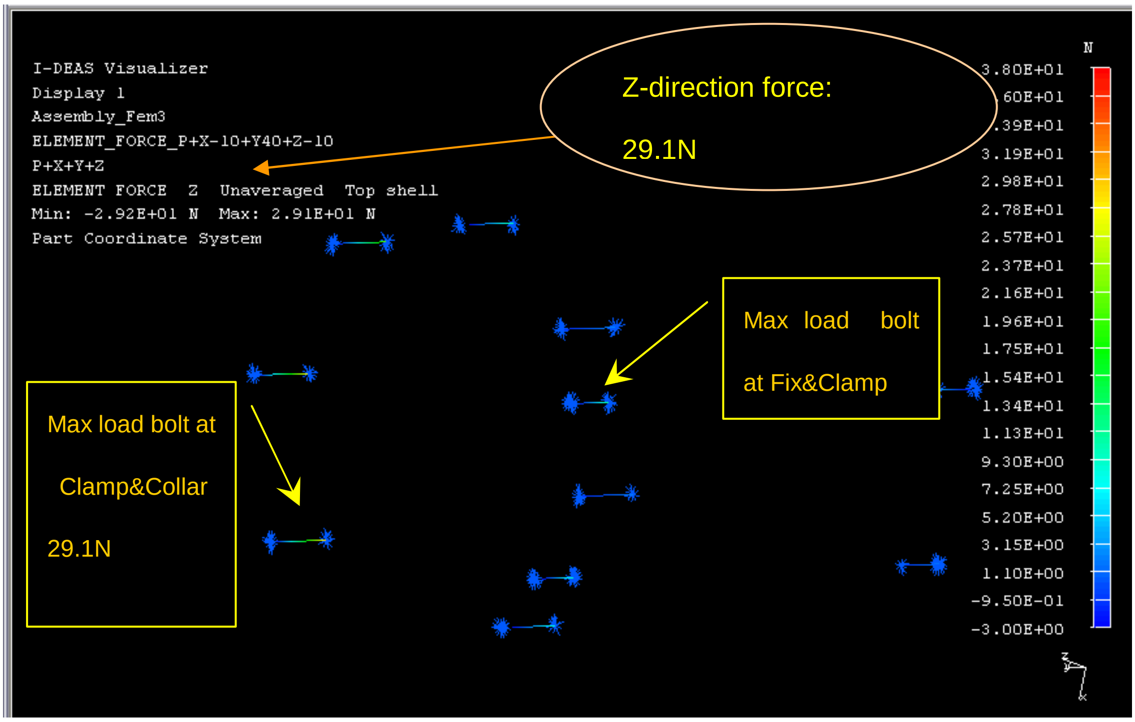


Figure 5-40 Clamp&Collar/ Fix&Clamp element Z-Direction forces; Load case (-10,40,-10)g

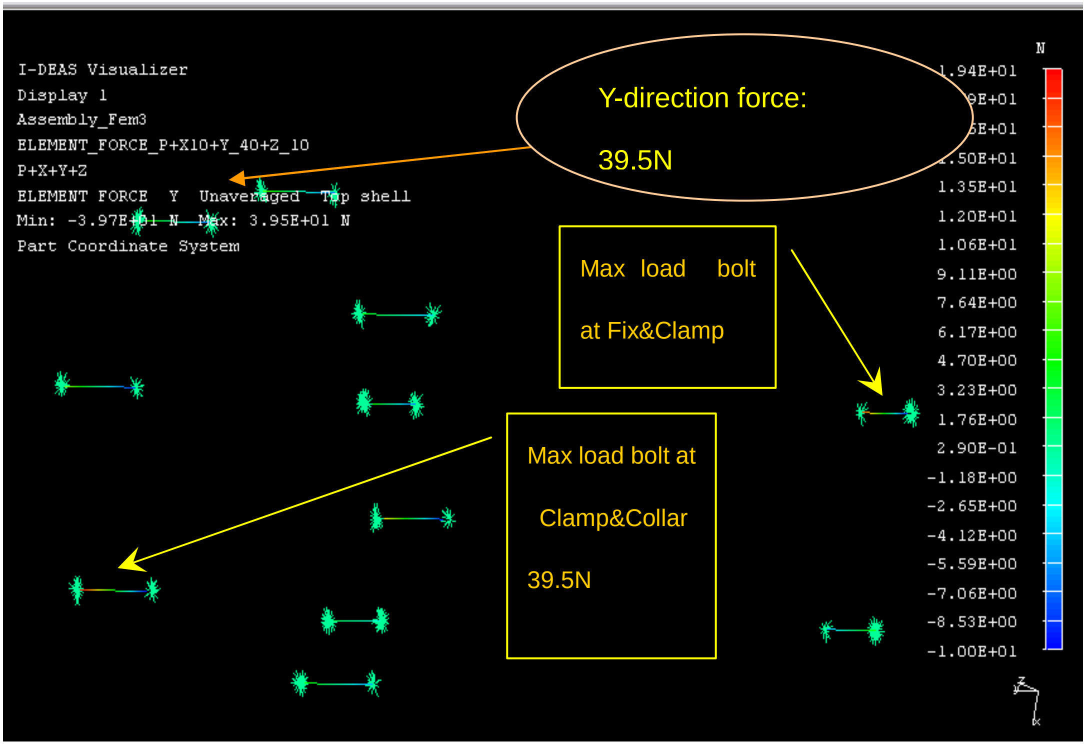


Figure 5-41 Clamp&Collar/ Fix&Clamp element Y-Direction forces; Load case (10,-40,-10)g

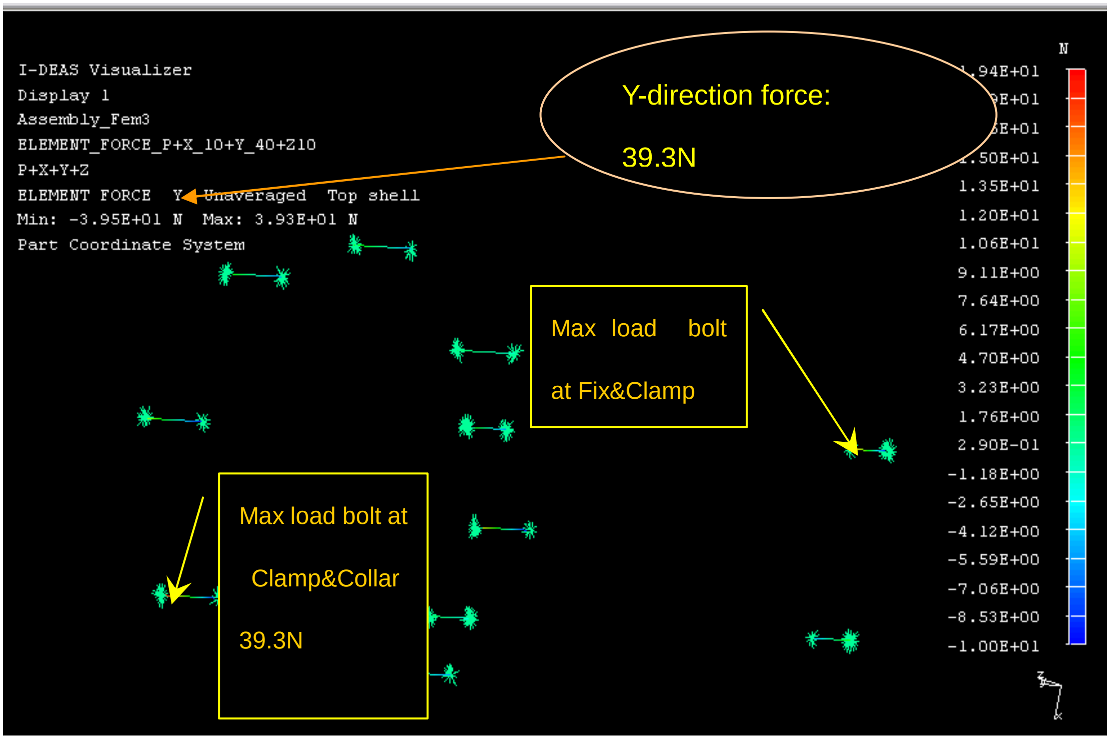


Figure 5-42 Clamp&Collar/ Fix&Clamp element Y-Direction forces; Load case (-10,-40, 10)g

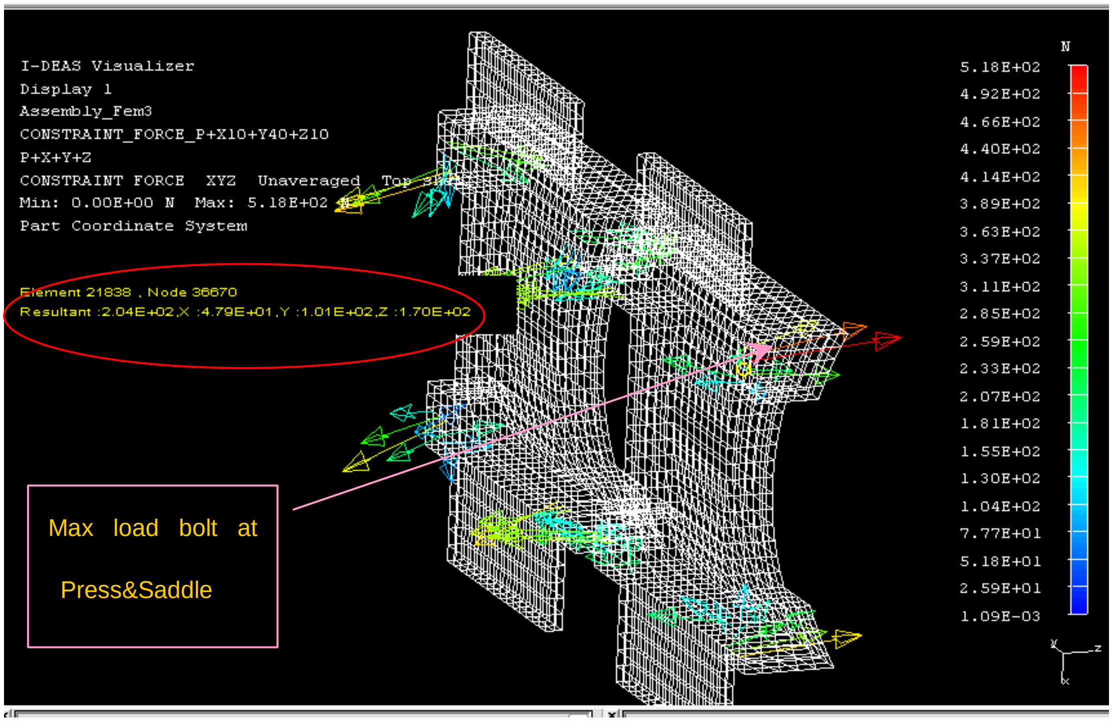


Figure 5-43 Peltier Saddle constraint forces at Bolts location; Load case (10,40,10)g

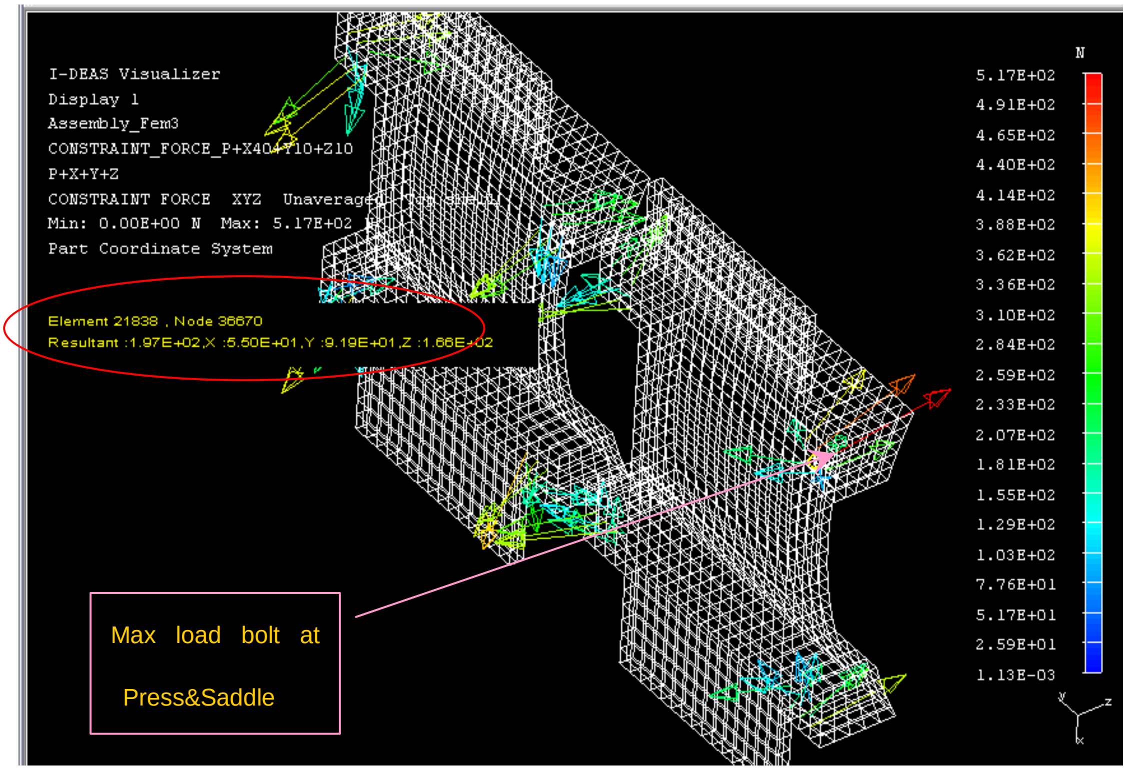


Figure 5-44 Peltier Saddle constraint forces at Bolts location; Load case (40,10,10)g

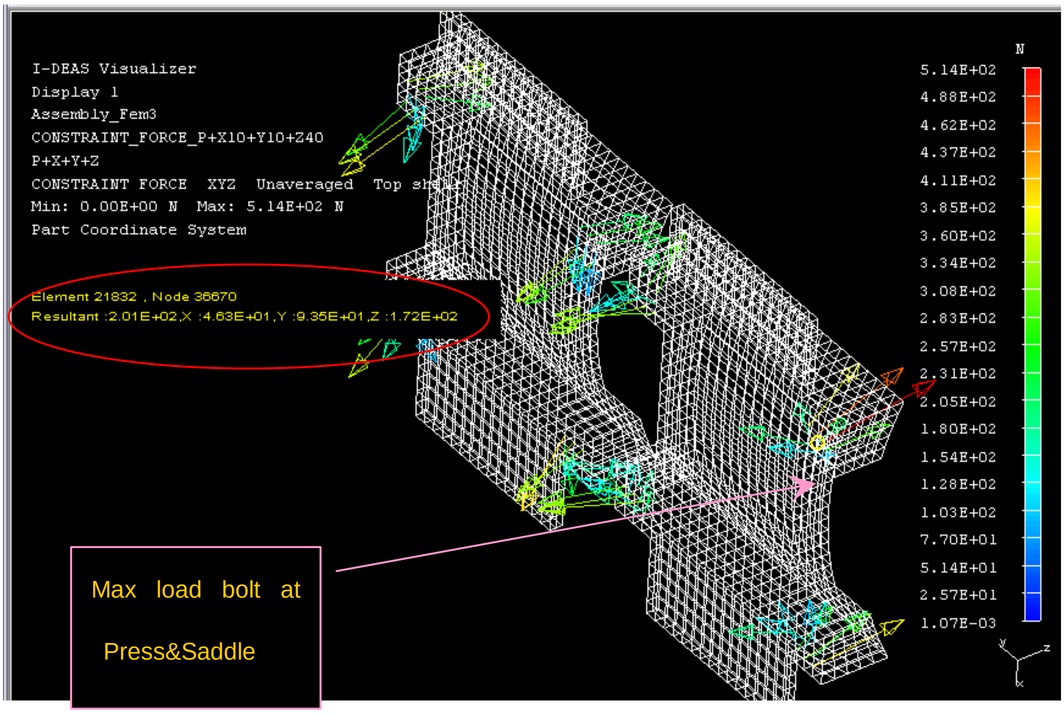


Figure 5-45 Peltier Saddle constraint forces at Bolts location; Load case (10,10,40)g

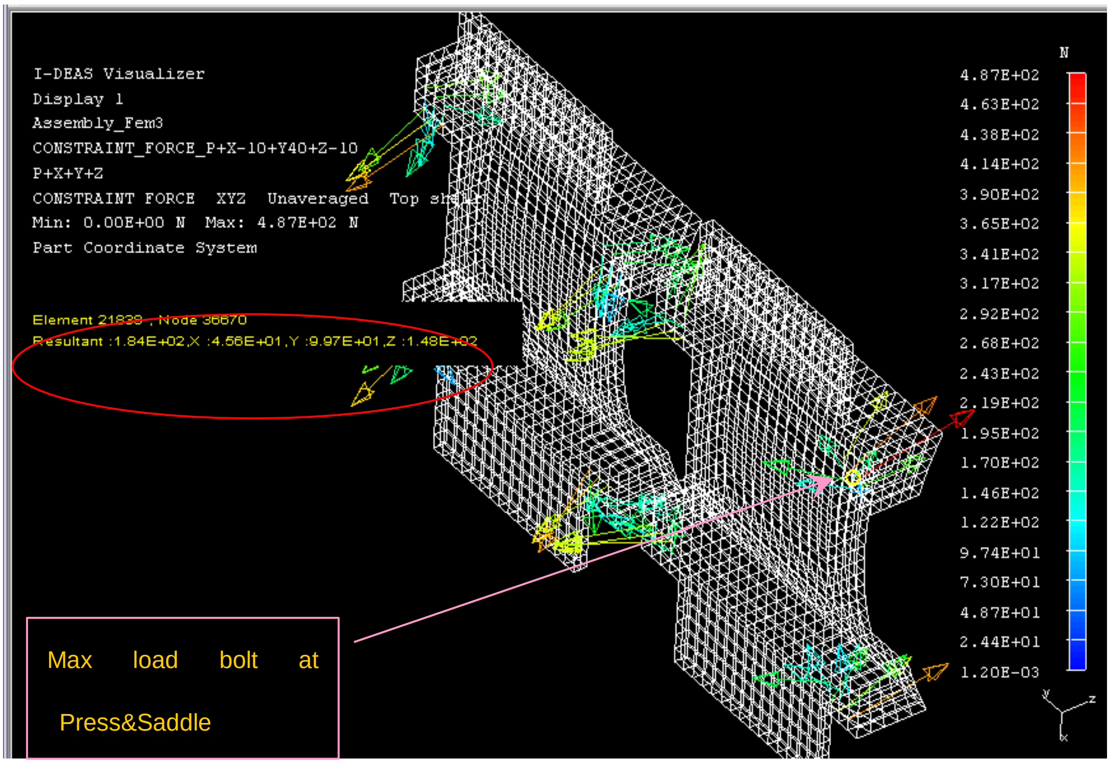


Figure 5-46 Peltier Saddle constraint forces at Bolts location; Load case (-10,40,-10)g

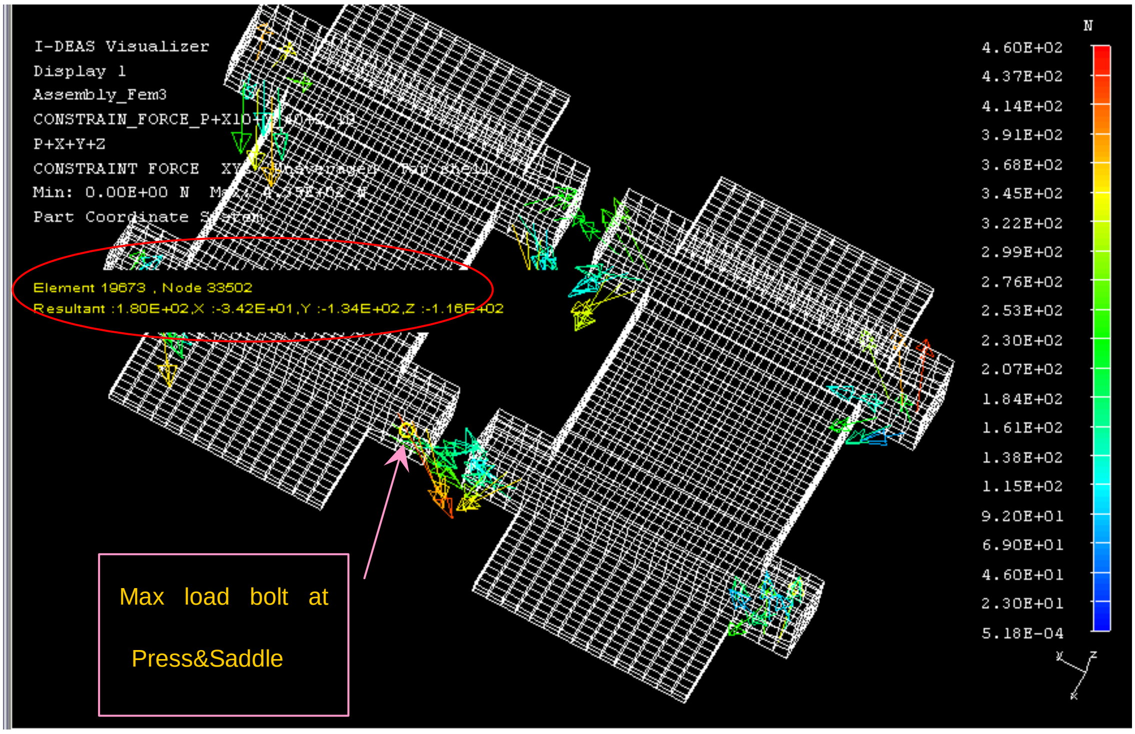


Figure 5-47 Peltier Saddle constraint forces at Bolts location; Load case (10,-40,-10)g

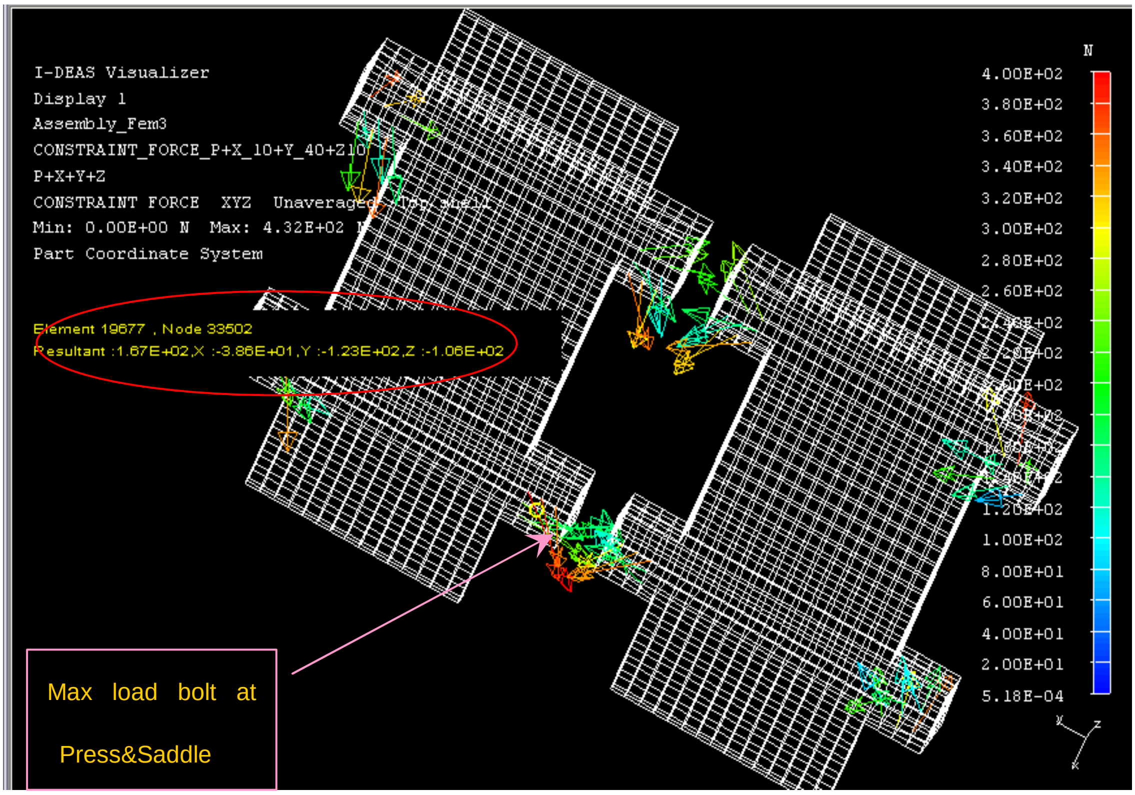


Figure 5-48 Peltier Saddle constraint forces at Bolts location; Load case (-10,-40, 10)g

5.2 Fail-Safe Analysis for launching/landing load cases

A Fail-Safe analysis was performed with the highest loaded fastener removed and all Margin of Safety are recalculated. The Factor of Safety used for fail-safe analysis is 1.0 for both yield and ultimate.

Table 5-13 Bolts removed details

Fail-Safe Analysis					
Load Case	**Acceleration(g)**			***Removed Bolts***	
	x	**y**	**z**	***Part***	***Bolt Number***
1	10	40	10	Clamp Assembly	1
2	40	10	10	Clamp Assembly	1
3	10	10	40	Clamp Assembly	1
4	-10	40	-10	Clamp Assembly	2
5	10	-40	-10	Clamp Assembly	3
6	-10	-40	10	Clamp Assembly	2

The Von Mises stress, Max Principal stress and maximum displacement under different load cases of the accumulator assembly are listed from Table 5-14 to Table 5-225.

5.2.1 The location of Removed bolt's.

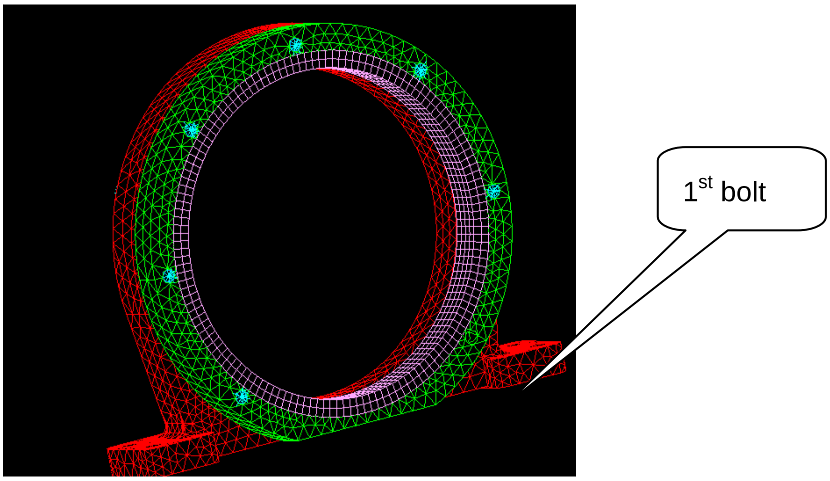


Figure 5-49 Removed 1st bolt

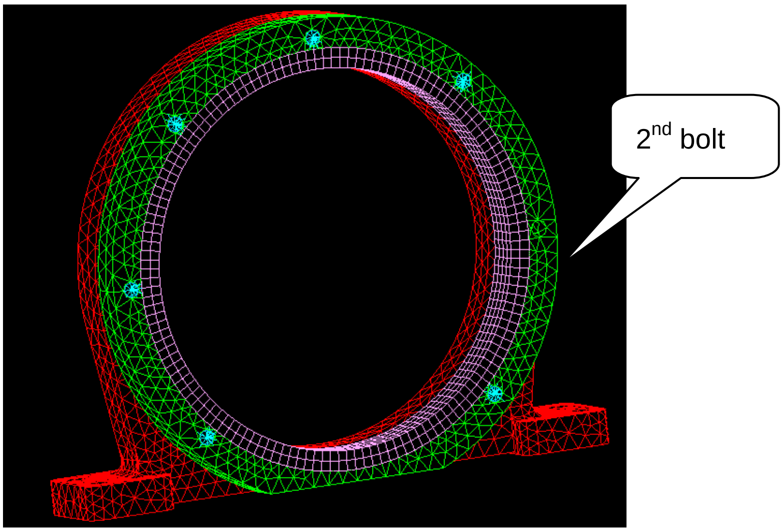


Figure 5-50 Removed 2nd bolt

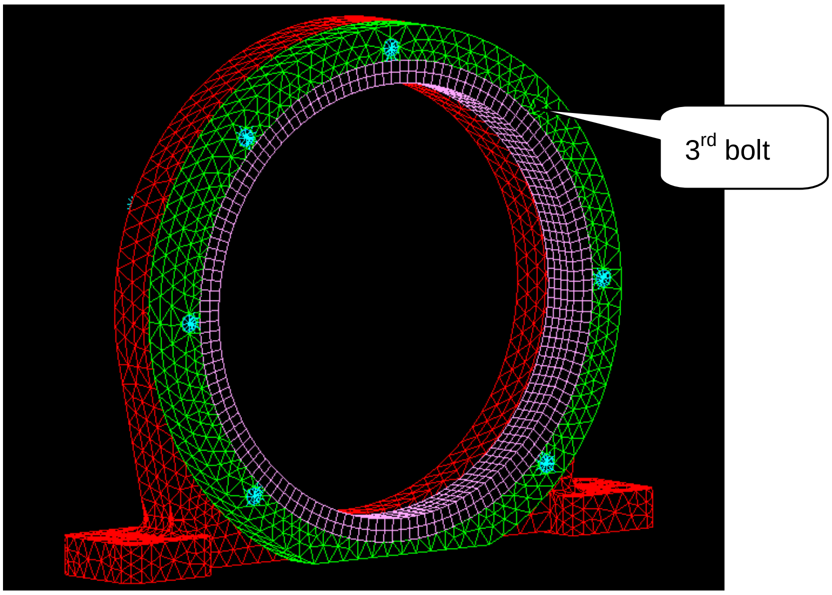


Figure 5-51 Removed 3rd bolt

5.2.2 Fail safe Stress: under Pressure and Six accelerations cases, after removed bolt.

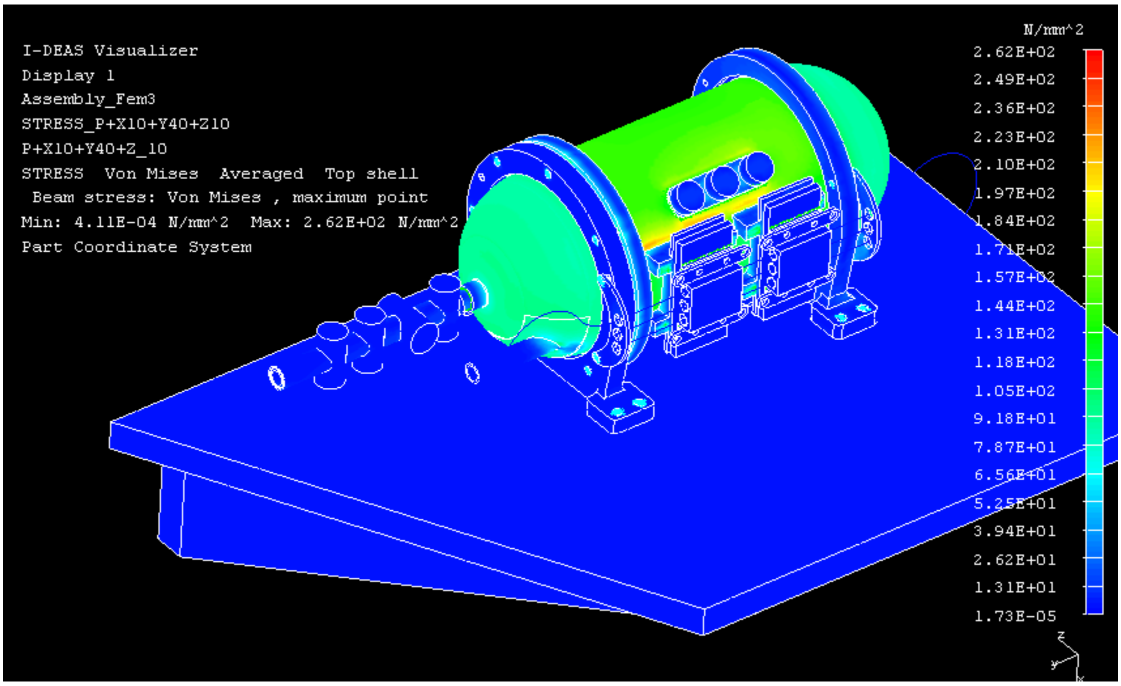


Figure 5-52 Fail-safe Analysis Removed 1st bolt-Stress: P+X10+Y40+Z10

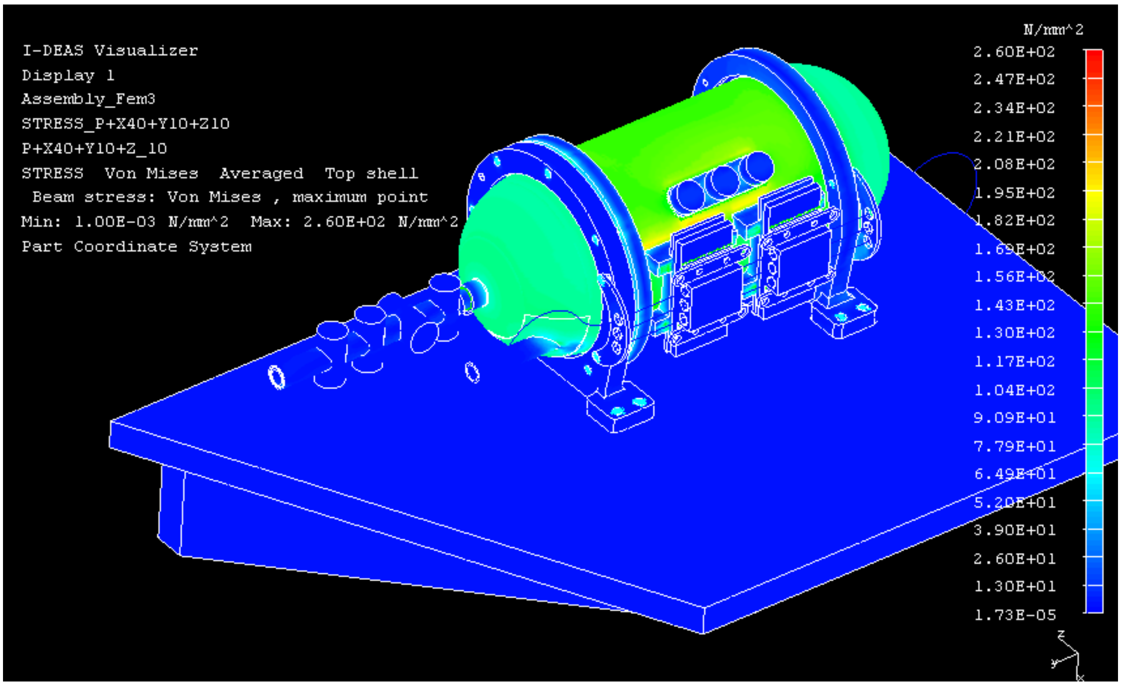


Figure 5-53 Fail-safe Analysis Removed 1st bolt-Stress: P+X40+Y10+Z10

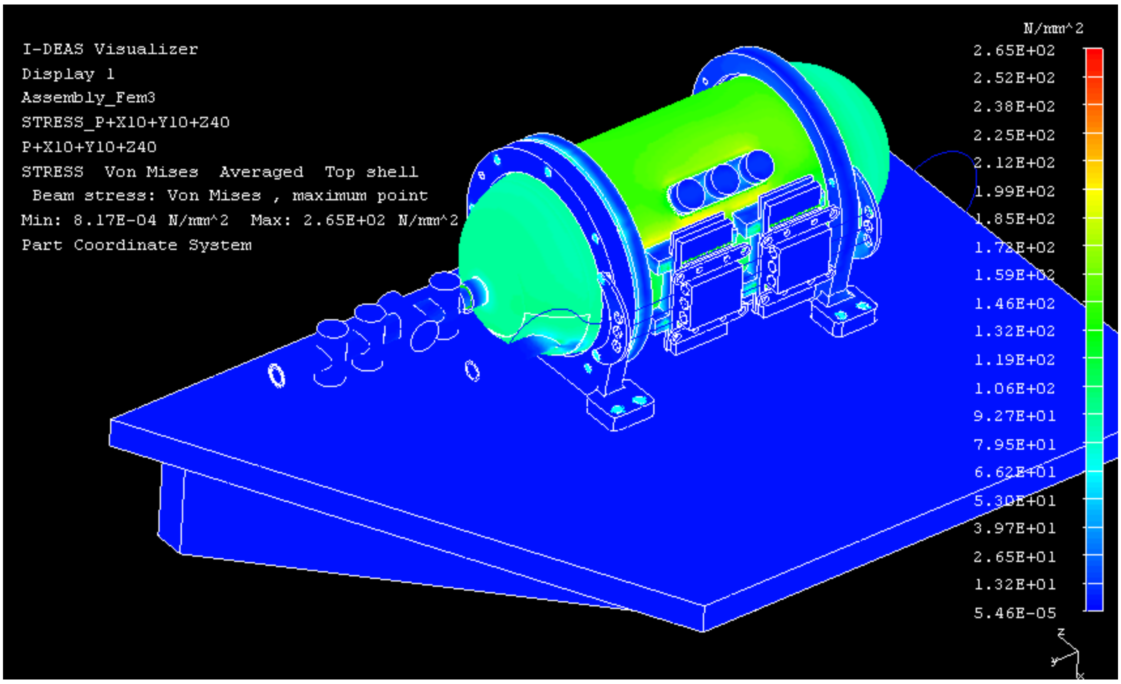


Figure 5-54 Fail-safe Analysis Removed 1st bolt-Stress: P+X10+Y10+Z40

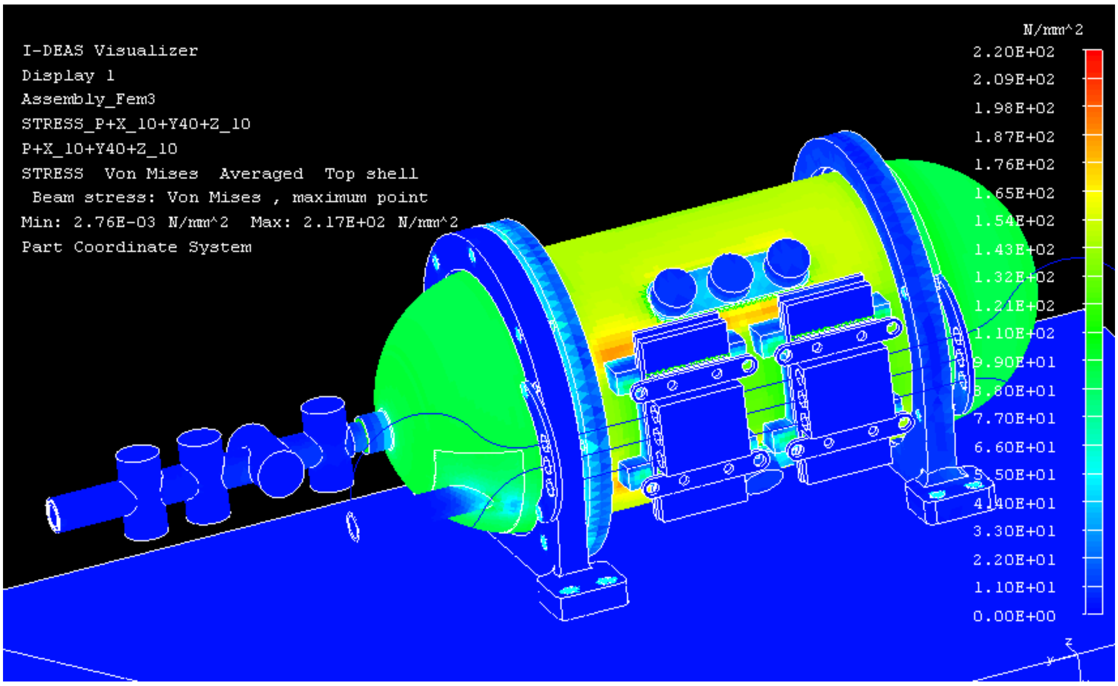


Figure 5-55 Fail-safe Analysis Removed 2nd bolt -Stress: P+X10+Y40+Z_10

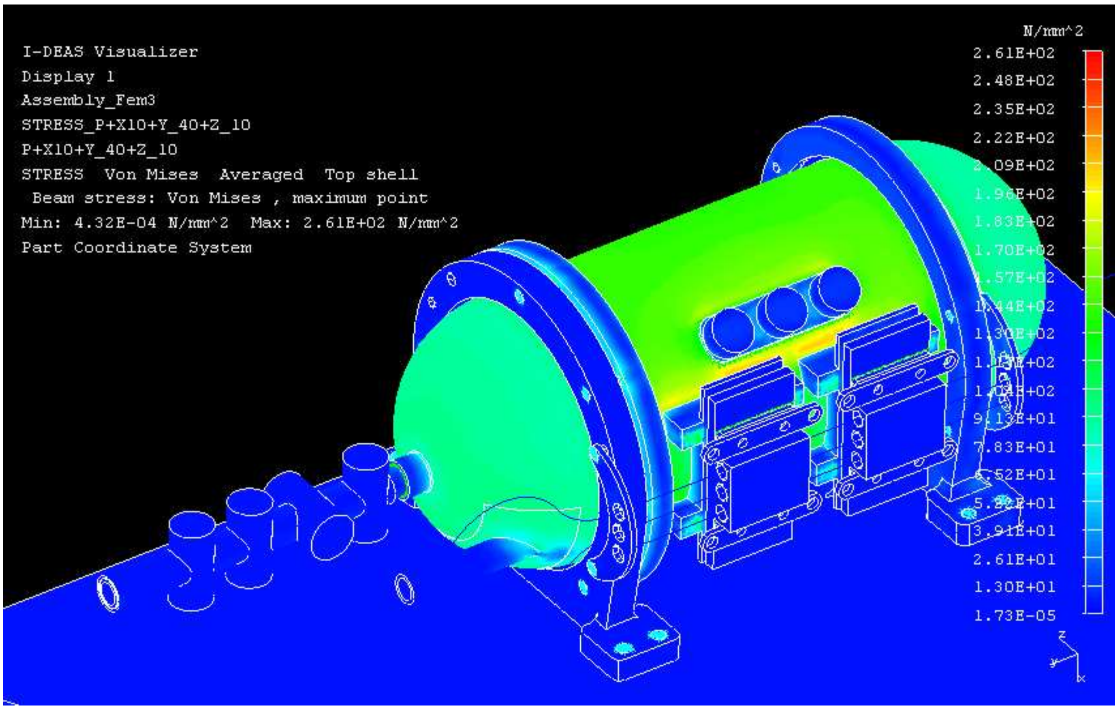


Figure 5-56 Fail-safe Analysis Removed 3rd bolt -Stress: P+X10+Y_40+Z_10

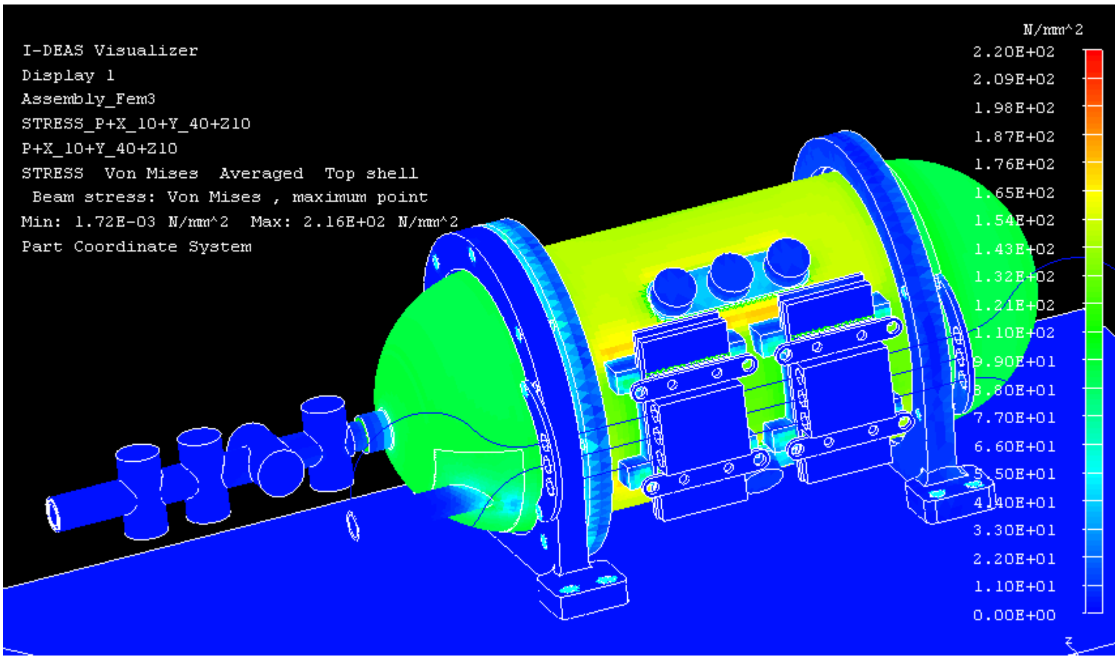


Figure 5-57 Fail-safe Analysis Removed 2nd bolt -Stress: P+X_10+Y_40+Z10

5.2.3 Fail safe Displacement: under Pressure and Six accelerations cases, after removed bolt.

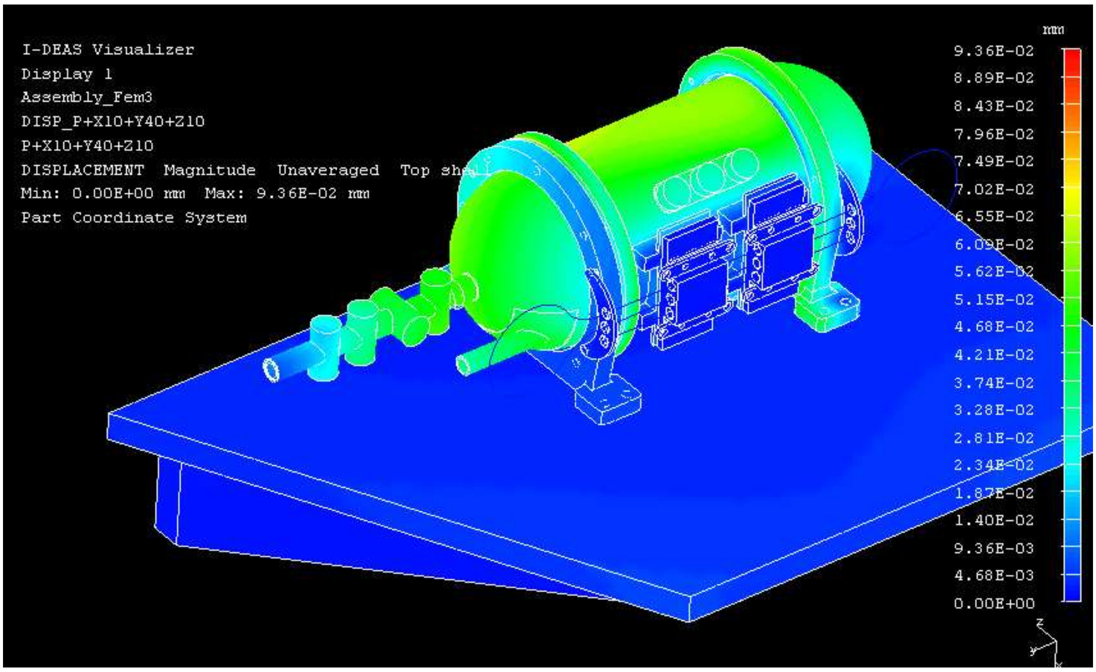


Figure 5-58 Fail-safe Analysis: Removed 1st bolt -Displacement: P+X10+Y40+Z10

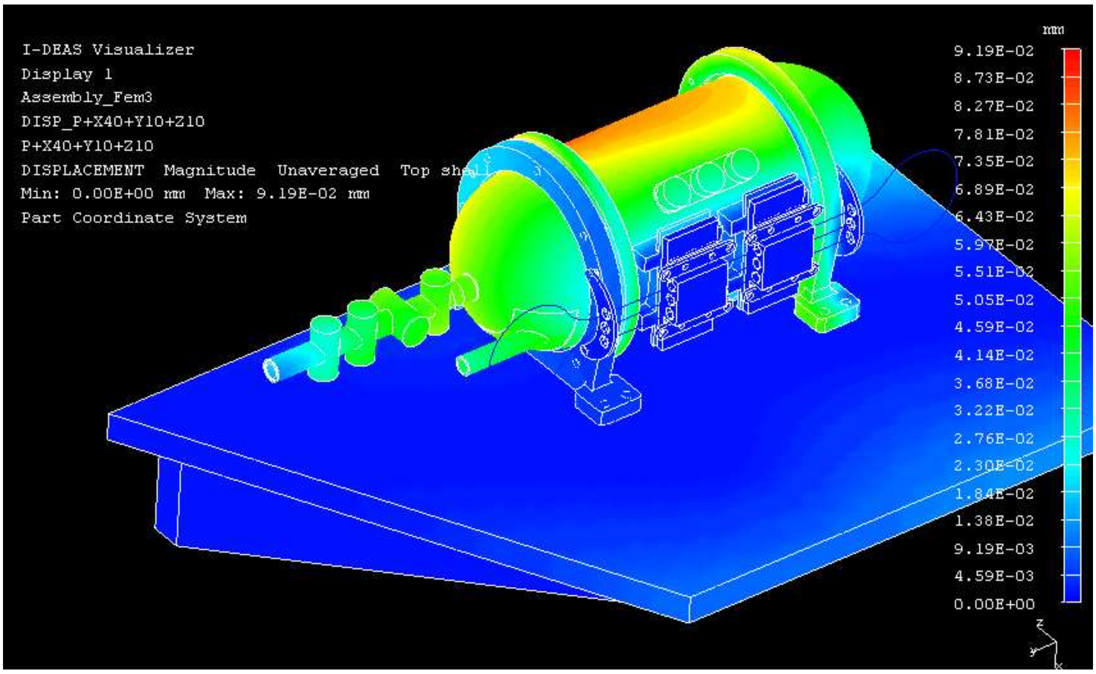


Figure 5-59 Fail-safe Analysis: Removed 1st bolt -Displacement: P+X40+Y10+Z10

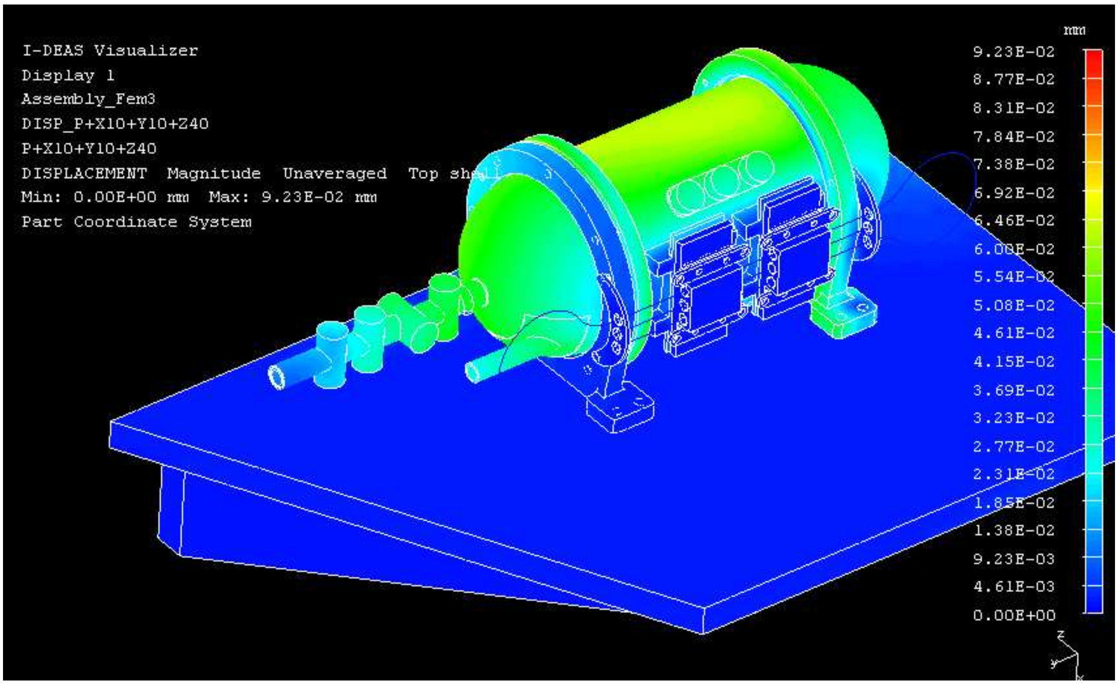


Figure 5-60 Fail-safe Analysis: Removed 1st bolt -Displacement: P+X10+Y10+Z40

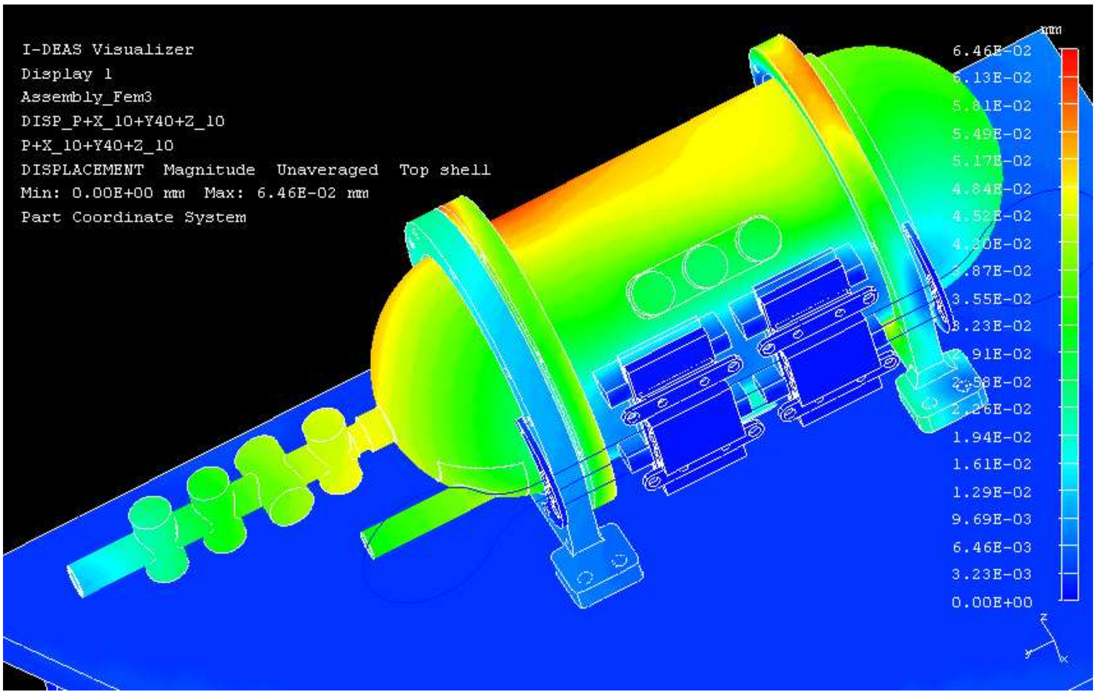


Figure 5-61 Fail-safe Analysis: Removed 2nd bolt-Displacement: P+X_10+Y40+Z_10

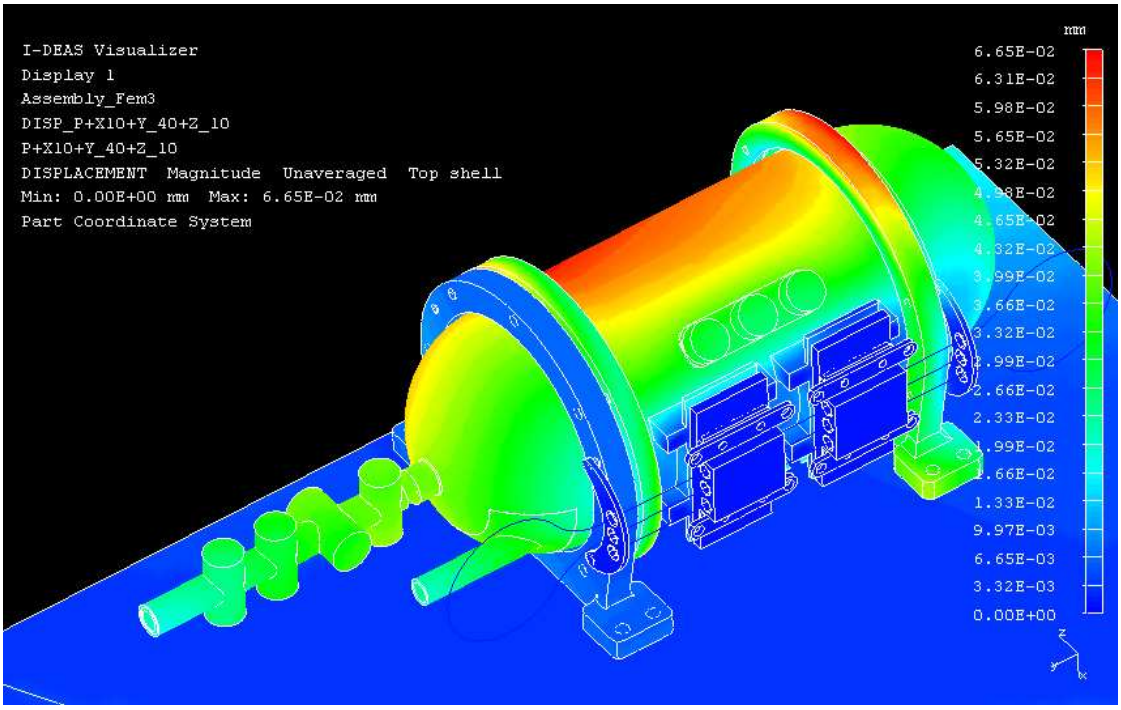


Figure 5-62 Fail-safe Analysis: Removed 3rd bolt-Displacement: P+X10+Y_40+Z_10

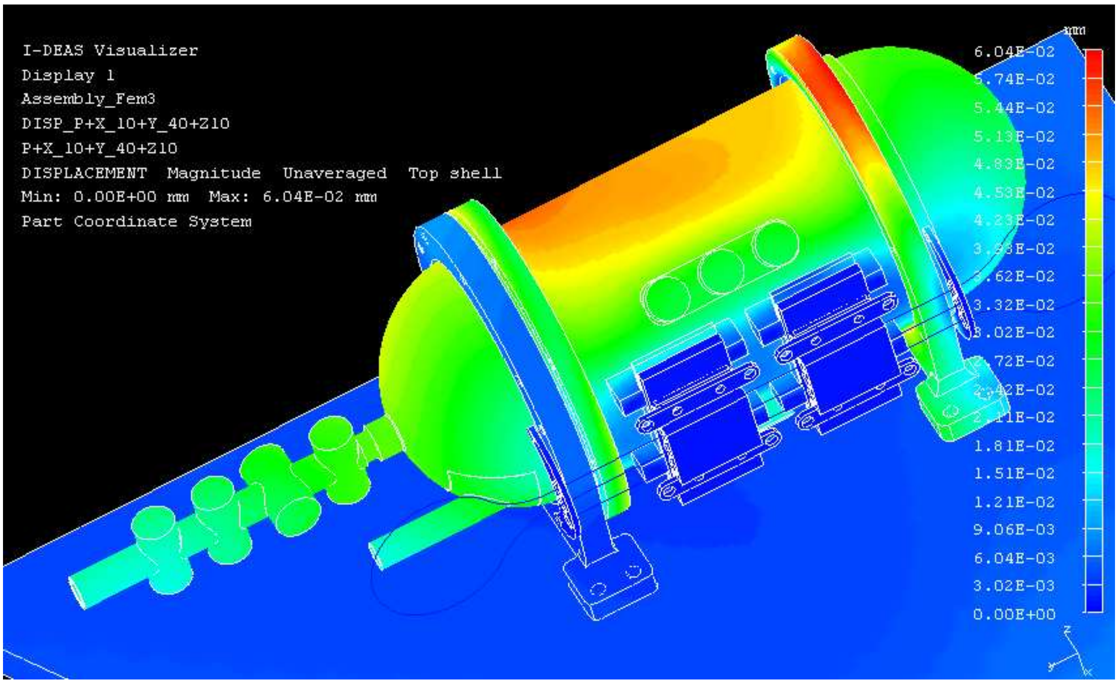


Figure 5-63 Fail-safe Analysis: Removed 2nd bolt-Displacement: P+X_10+Y_40+Z10

5.2.4 Fail safe Result: Load Combination of Pressure and Six acceleration cases.

Table 5-14 **Restraints** *at Base Plate Bolts Locations*

Restraints *at Base Plate Bolts Locations*					
Ux	Uy	Uz	Rx	Ry	Rz
0	0	0	0	0	0

Table 5-15 Accumulator Stresses, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***Accumulator Material: 316Ln***				
Load	Acceleration *(g)*			Max Stress *[N/mm2]*		Displacement	Margin of Safety	
Case	x	y	z	*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	10	40	10	216	231	0.0683	0.55	1.81
2	40	10	10	213	228	0.0826	0.57	1.85
3	10	10	40	217	232	0.0648	0.54	1.80
4	-10	40	-10	217	232	0.0646	0.54	1.80
5	10	-40	-10	214	229	0.0662	0.57	1.84
6	-10	-40	10	216	232	0.0554	0.55	1.80

Table 5-16 ***Peltier Copper saddle*** Stresses, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***Peltier Copper saddle Material: copper***				
Load	Acceleration *(g)*			Max Stress *[N/mm2]*		Displacement	Margin of Safety	
Case	x	y	z	*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	10	40	10	67.4	74.3	0.0192	0.19	1.96
2	40	10	10	68.2	78.5	0.0216	0.17	1.80
3	10	10	40	58.7	62.3	0.0198	0.36	2.53

4	-10	40	-10	72.8	76.8	0.0179	0.10	1.86
5	10	-40	-10	56.8	63.8	0.0201	0.41	2.45
6	-10	-40	10	57.5	58.6	0.0186	0.39	2.75

Table 5-17 ***Fixed Bracket Assembly*** Stresses, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***Fixed Bracket Assembly* *Material: 316L***				
Load Case	Acceleration *(g)*			Max Stress *[N/mm2]*		Displacement *(mm)*	Margin of Safety	
	x	y	z	*Von Mises*	*Max Principal*		Yield	Ultimate
1	10	40	10	90.8	87.8	0.0694	1.64	5.26
2	40	10	10	91.2	88	0.0828	1.63	5.25
3	10	10	40	90.6	87.7	0.0641	1.65	5.27
4	-10	40	-10	92	89	0.0635	1.61	5.18
5	10	-40	-10	91.7	89.1	0.0594	1.62	5.17
6	-10	-40	10	91.3	88.3	0.0487	1.63	5.23

Table 5-18 ***Sliding Bracket*** Stresses, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS	
Loads Cases	***Sliding Bracket* *Material: Al 7075***

Load Case	Acceleration (g) x	y	z	Max Stress [N/mm2] Von Mises	Max Principal	Displacement (mm)	Margin of Safety Yield	Ultimate
1	10	40	10	34.7	33.9	0.0936	10.33	12.83
2	40	10	10	40.5	47.6	0.0919	8.70	8.85
3	10	10	40	35.6	35.4	0.0923	10.04	12.24
4	-10	40	-10	40.9	37.9	0.0572	8.61	11.37
5	10	-40	-10	49.7	34.6	0.0665	6.91	12.55
6	-10	-40	10	36.6	34.3	0.0604	9.74	12.67

Table 5-19 ***Heat Pipe Assembly*** Stress, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***Heat Pipe Assembly Material: 316L***				
Load Case	Acceleration (g) x	y	z	Max Stress [N/mm2] Von Mises	Max Principal	Displacement (mm)	Margin of Safety Yield	Ultimate
1	10	40	10	93.4	47.4	0.053	1.57	10.60
2	40	10	10	116	54	0.622	1.07	9.19
3	10	10	40	90	47.6	0.0469	1.67	10.55
4	-10	40	-10	61.4	32.5	0.0481	2.91	15.92
5	10	-40	-10	64.2	28.9	0.0448	2.74	18.03
6	-10	-40	10	60.1	29.5	0.0351	2.99	17.64

Table 5-20 ***Peltier Pipe Fixed*** Stress, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***Peltier Pipe Fixed Material: 316L***				
Load Case	Acceleration *(g)*			Max Stress *[N/mm2]*		Displacement	Margin of Safety	
	x	y	z	*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	10	40	10	38.6	26.8	0.0342	5.22	19.52
2	40	10	10	40.4	27	0.0349	4.94	19.37
3	10	10	40	37.2	26	0.333	5.45	20.15
4	-10	40	-10	29	22.5	0.0277	7.28	23.44
5	10	-40	-10	33.8	31.6	0.0183	6.10	16.41
6	-10	-40	10	32	28.7	0.0251	6.50	18.16

Table 5-21 ***Peltier HE& Spring Support*** Stress, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***Peltier Heat Exchanger & Spring Support Material: Copper***				
Load Case	Acceleration *(g)*			Max Stress *[N/mm2]*		Displacement	Margin of Safety	
	x	y	z	*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	10	40	10	2.12	0.786	0.000251	36.74	278.90
2	40	10	10	1.35	0.974	0.000381	58.26	224.87
3	10	10	40	1.17	1.09	0.000282	67.38	200.83

4	-10	40	-10	1.06	0.789	0.000231	74.47	277.83
5	10	-40	-10	1.49	0.559	0.000252	52.69	392.56
6	-10	-40	10	0.621	0.285	0.000176	127.82	770.93

Table 5-22 ***TS &Peltier heat exchanger press*** Stress, Displacements and Margin of fail Safety

FAIL SAFE ANALYSIS								
Loads Cases				***TS &Peltier heat exchanger press*** ***Material: 316L***				
Load Case	Acceleration *(g)*			Max Stress *[N/mm2]*		Displacement *(mm)*	Margin of Safety	
	x	y	z	*Von Mises*	*Max Principal*		Yield	Ultimate
1	10	40	10	117	126	0.0438	1.05	3.37
2	40	10	10	121	131	0.0459	0.98	3.20
3	10	10	40	111	119	0.0465	1.16	3.62
4	-10	40	-10	113	122	0.0369	1.12	3.51
5	10	-40	-10	113	122	0.0386	1.12	3.51
6	-10	-40	10	108	116	0.0366	1.22	3.74

Table 5-23 Fail-Safe Accu.Bracket Clamp&Collar Bolt Element Force and MoS **(Preload: 65%)**

Accu.Bracket Clamp&Collar Bolt element force and MofSafety Calculation（Fail Safe）									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	

1 (10.40.10)	21.1	23.2	-31.4	37.8	8.44	23.2	5.18	2.8	0.38
2 (40.10.10)	36.4	19.4	-30.8	47.7	10.65	19.4	4.33	3.2	0.36
3 (10.10.40)	21.5	23.6	-29.8	36.7	8.19	23.6	5.27	2.8	0.38
4 (-10.40.-10)	0.51	60.8	-31.7	31.7	7.08	60.8	13.57	3.9	0.34
5 (10.-40.-10)	8.6	25.3	-29.5	30.7	6.85	25.3	5.65	2.5	0.39
6 (-10.-40.10)	0.04	37.3	-27.3	27.3	6.09	37.3	8.33	2.8	0.38

Table 5-24 Fail-Safe PipeFix&Clamp Bolt Element Force and MoS Calculation(Preload: 65%)

PipeFix&Clamp Bolt element force and MofSafety Calculation（Fail Safe ）									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
1 (10.40.10)	4.47	-53.1	-10.4	11.3	2.52	53.1	11.85	0	0.5
2 (40.10.10)	4.55	-49.6	-3.72	5.88	1.31	49.6	11.07	0	0.5
3 (10.10.40)	4.68	-51.3	-10.1	11.1	2.48	51.3	11.45	0	0.5
4 (-10.40.-10)	3.03	-28.2	-6.49	7.16	1.60	28	6.25	0	0.5
5 (10.-40.-10)	-9.07	19.4	9.13	12.9	2.88	19.4	4.33	0	0.5
6 (-10.-40.10)	-6.11	28.2	11	12.6	2.81	28.2	6.29	0	0.5

Table 5-25 Fail-Safe Press&Saddle Bolt Contraint Force and MoS Calculation(Preload: 65%)

Press&Saddle* Bolt Contraint *force and MofSafety Calculation（Fail Safe）									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
1（10.40.10）	48.5	111	199	121	27	199	44.4	0	0.19
2（40.10.10）	62.2	93.1	187	112	25	187	41.7	0	0.20
3（10.10.40）	45.7	96.6	201	107	23.88	201	44.87	0	0.19
4（-10.40.-10）	43.8	109	160	117	26.12	160	35.71	0	0.20
5（10.-40.-10）	-31.6	-148	-120	151	33.71	120	26.49	0	0.20
6（-10.-40.10）	-39.3	-129	-103	135	30.13	103	23	0	0.20

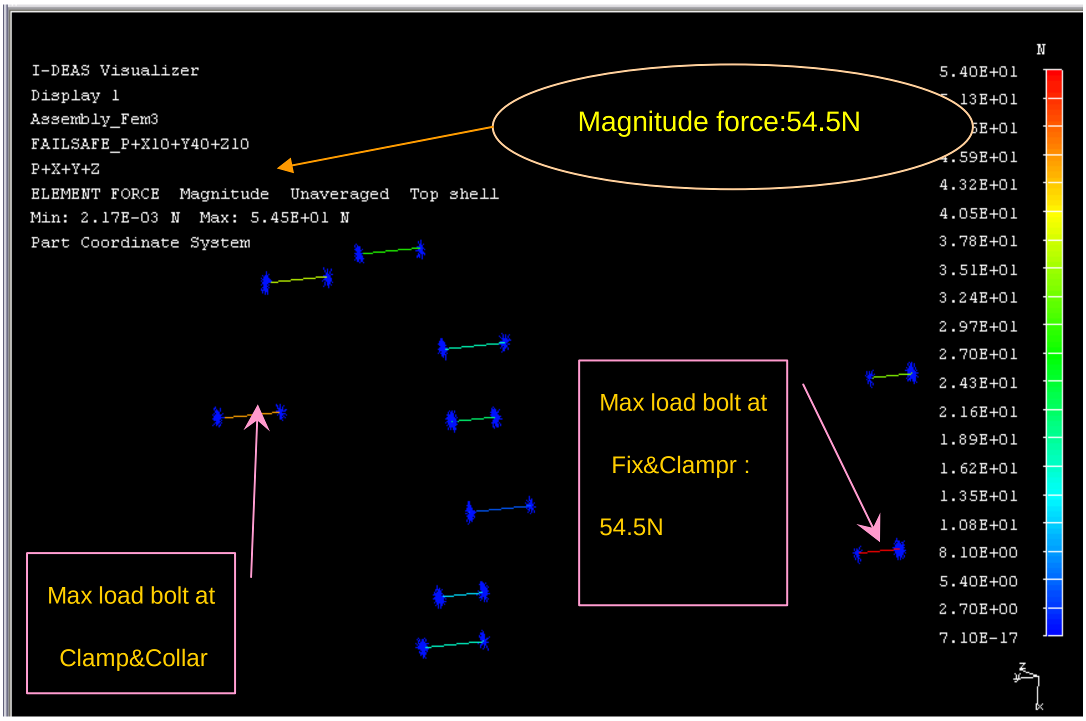


Figure 5-64 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element Magnitude forces;

Load case: P+X10+Y40+Z10

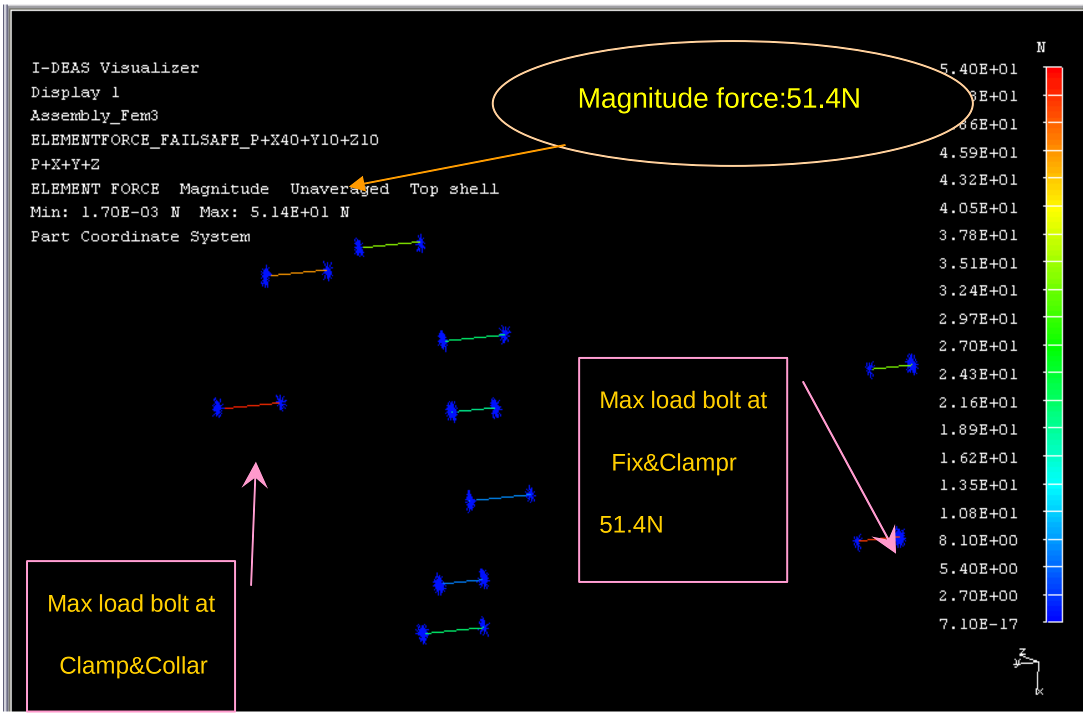


Figure 5-65 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element Magnitude forces

(Load case: P+X40+Y10+Z10)

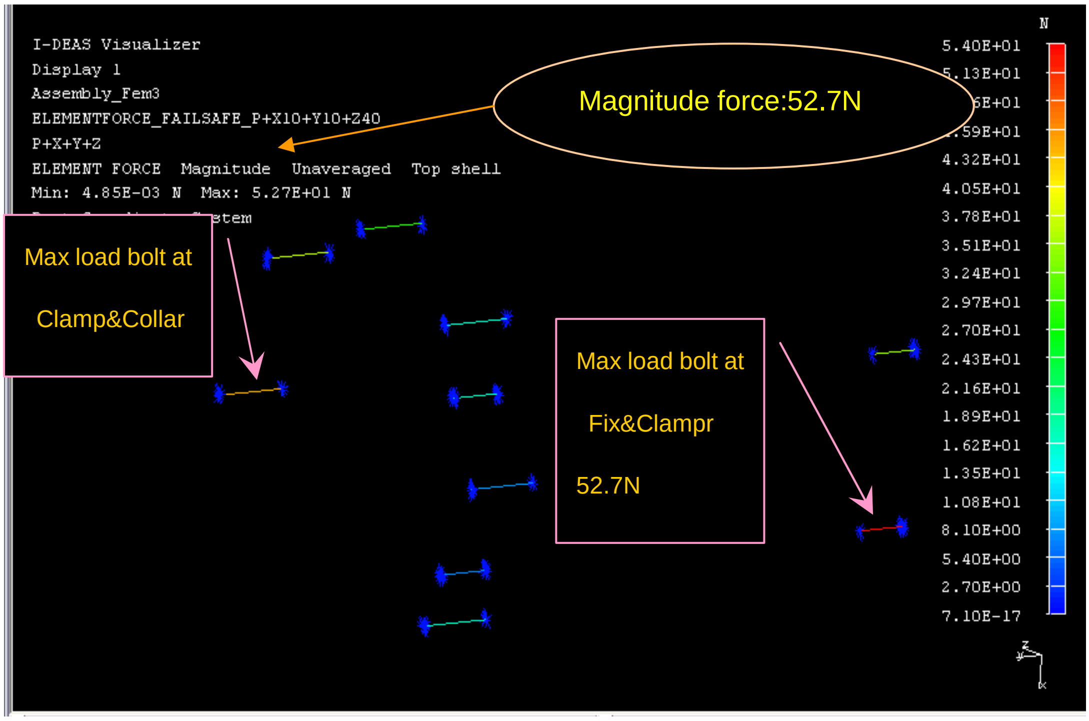


Figure 5-66 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element Magnitude forces;

Load case: P+X10+Y10+Z40

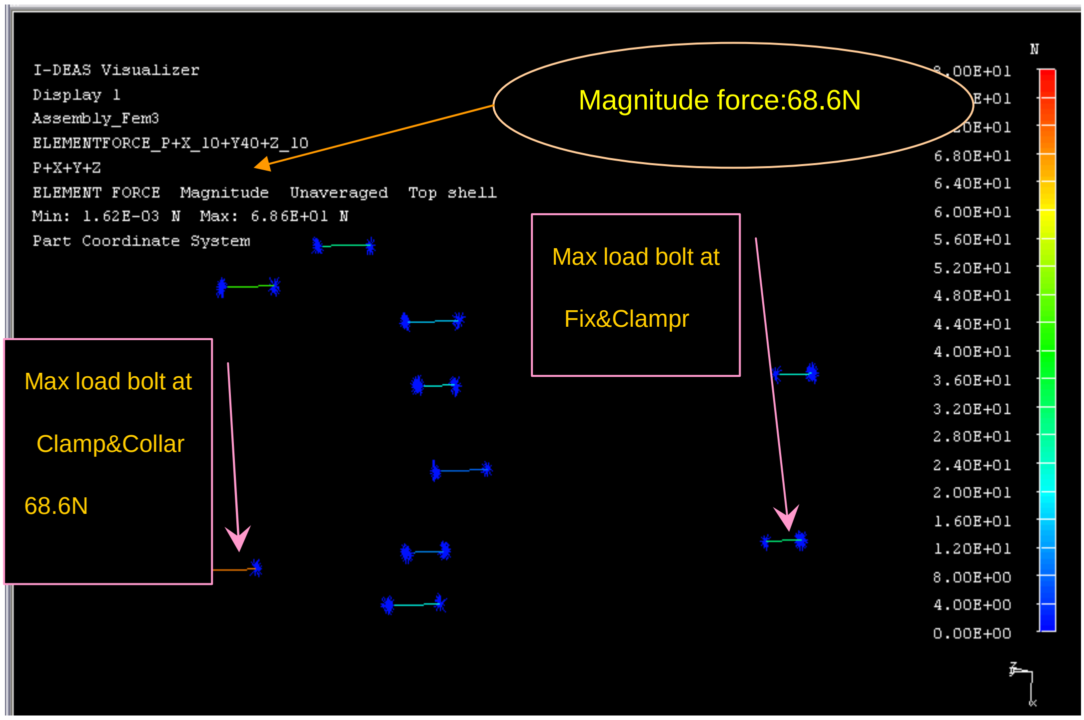


Figure 5-67 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element Magnitude force

(P+X_10+Y40+Z_10)

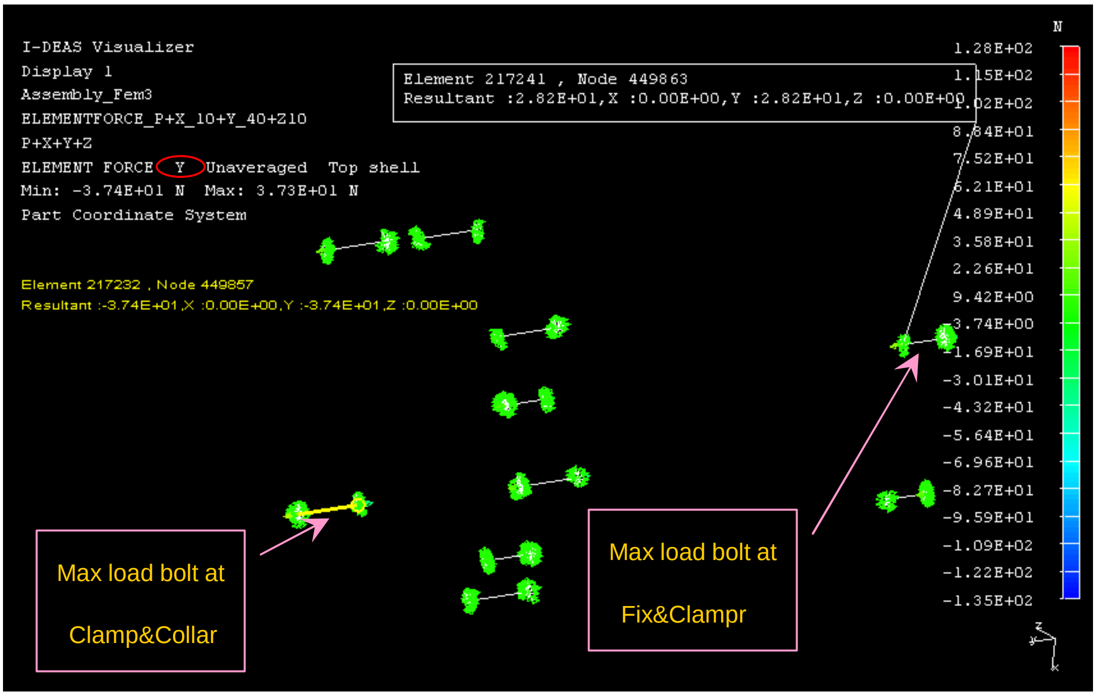


Figure 5-68 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element Y-Direction forces;

P+X_10+Y_40+Z10

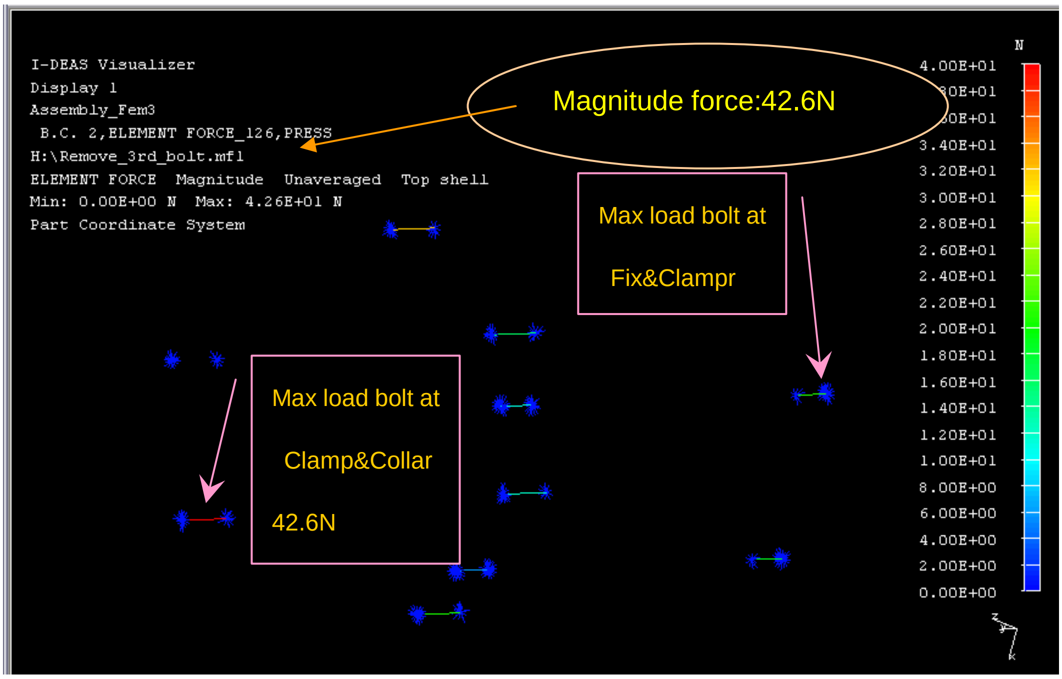


Figure 5-69 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element forces;

Load case P+X10+Y_40+Z_10

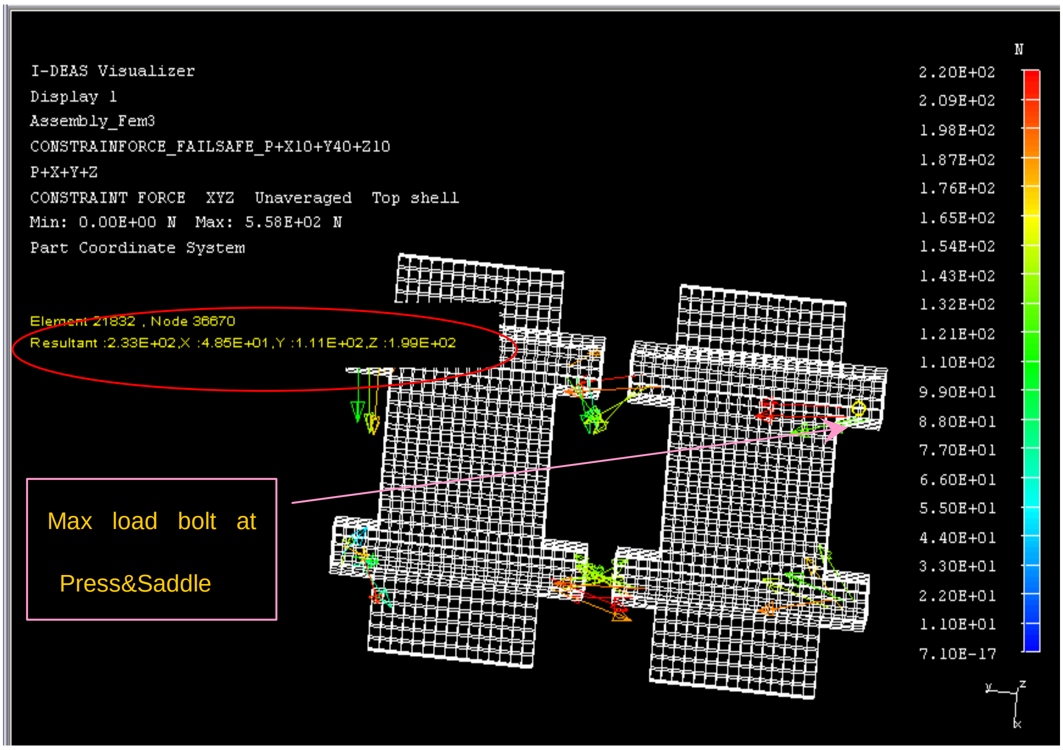


Figure 5-70 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location;

Load case：P+X10+Y40+Z10

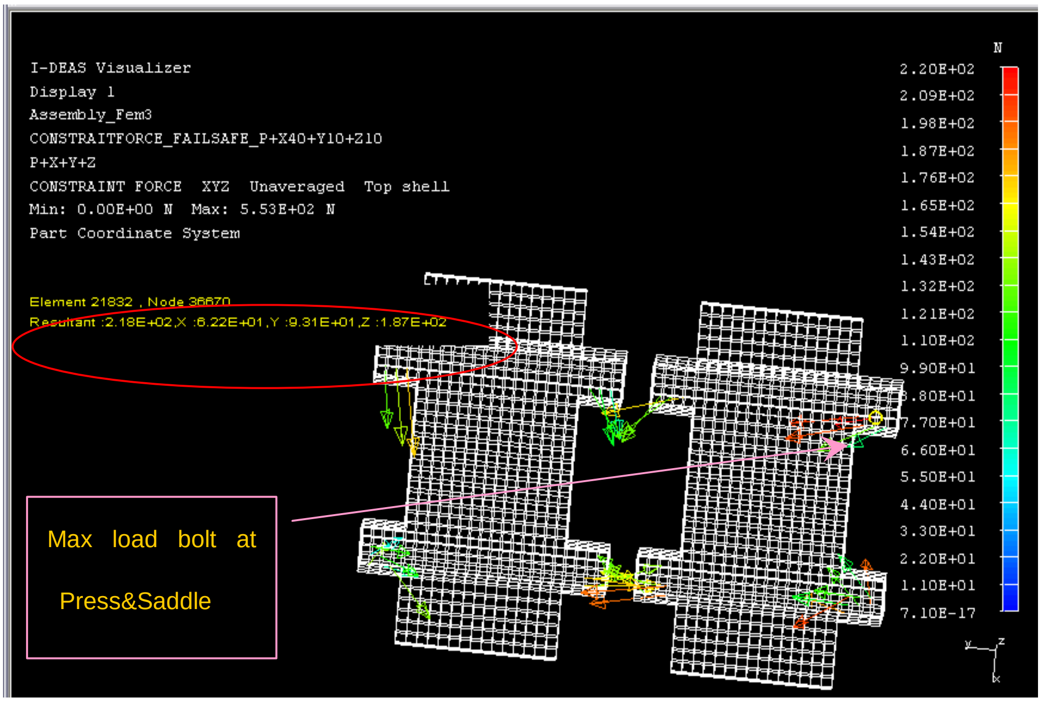


Figure 5-71 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case： P+X40+Y10+Z10

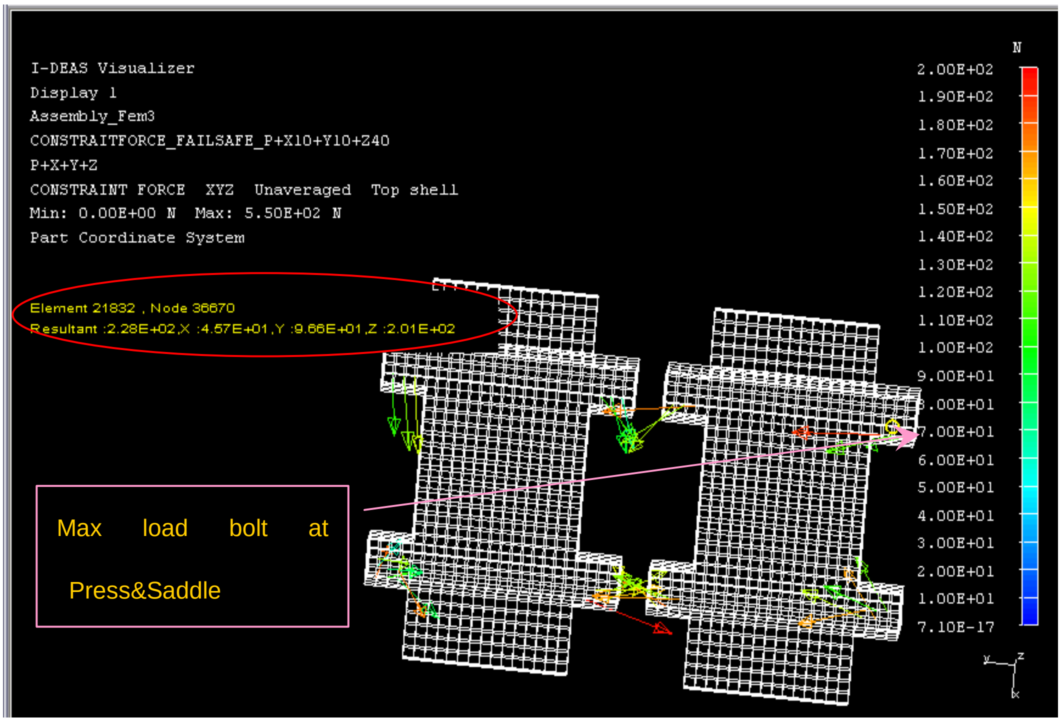


Figure 5-72 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case： P+X10+Y10+Z40

Figure 5-73 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case：P+X_10+Y_40+Z10

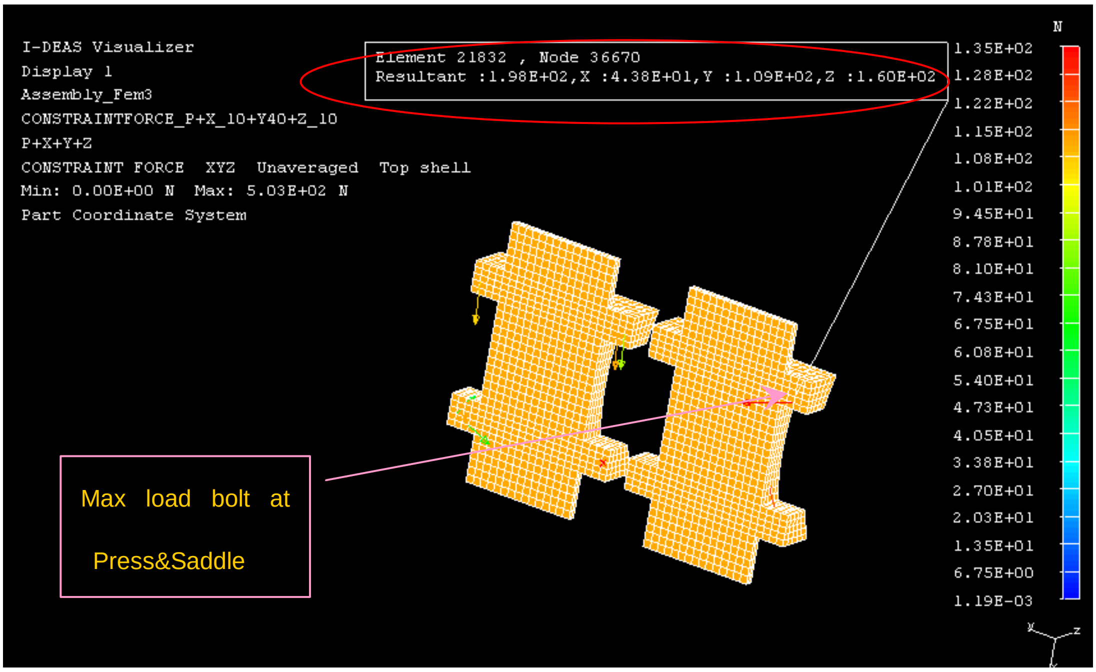


Figure 5-74 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case：P+X_10+Y40+Z_10

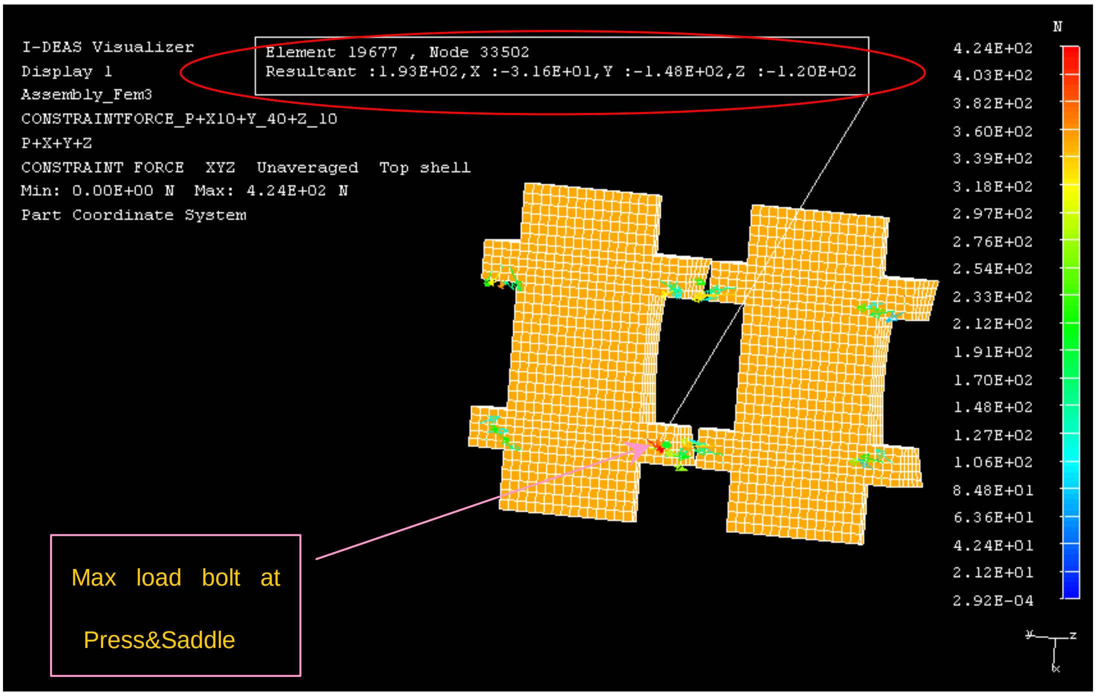


Figure 5-75 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case：P+X10+Y_40+Z_10

6. STRUCTURE ANALYSIS FOR IN ORBIT LOAD CASES

6.1 Thermal analysis for the critical cases

The thermal analysis and stress analysis share the same FEM model described above, so that the stress analysis can use the results from thermal analysis directly.

6.1.1 Material Properties

Table 6-1 Material properties of Thermal Analysis

Component	material	Density	Thermal conductivity(W/mK)	Capacity(J/kgK)
Accumulator	SST	7960	16.3	500
Heater	SST	7960	16.3	500
Worked AHP	SST	7960	10000	500
HX	Copper	8960	380	386
Saddle	Copper	8960	380	386
Soldering material	Sn60Pb40	9340	50	150

The Heat load of Peltiers is defined on the touching surfaces of Peltiers and HXs, Saddles.

6.1.2 Thermal Coupling of touching surfaces

Thermal Coupling is used to define the thermal resistance between each touching surface. Here only the mechanically assembly surfaces are considered with resistance. The thermal coefficients of all the mechanically assembly surfaces are defined as $400W/m^2K$. All the thermal coefficients of touching surfaces considered in the thermal analysis are listed in Table 6-2.

Table 6-2 Thermal Coefficients of touching surfaces

	Bracket – Acc_Frange	HX_Press-HX	Peltier_Saddle-AccuTS_Saddle
K /$Wm^{-2}K^{-1}$	400	400	400

	HX-Peltier_Saddle
K /WmK^{-1}	20

The resistances of all the soldering surfaces are neglected in the thermal analysis since the thermal coefficient is about 3000W/m^2K which means the temperature gradient is not big, and this can be seen in RD10.

6.1.3 Boundary Condition Definition

Cases and Heat Load

Since all the heaters on the Heat Pipe are powered on, the Heat Load of Heaters is 75W; take notice to the placement of the heaters, if all the heaters are powered on, the heat load on the Heat Pipe is not even. If all the Peltiers are power on, the heat load of Peltiers is 100W. [RD10] As the loop is not running, the heat generated can not be dissipated away immediately; the boundary condition is similar to Case3 in RD10. The boundary conditions for the hot case are listed in Table 6-3.

Table 6-3 Boundary Conditions

Case	Description	Heaters/W	Peltiers/W
1	HP TS Switched	75	0
2	Peltier TS Switched	0	100
3	Combined of 1 and 2	75	100

Initial Temperature Definition

When Heat Pipe is operating normally, the initial temperature for the worst case which induced the maximum temperature of HP is 31℃. So, the initial temperature for the transient thermal analysis is 31℃. [RD10]

About the Peltier TS

As there is no “Peltier TS” available in this Stress-Model, the switching temperature can not be defined on “Peltier TS”. Since the mission of “Peltier TS” is keeping the temperature of Accumulator below 65℃, here we define the “maximum temperature of Accumulator” as our monitoring target:

1. When the maximum temperature of Accumulator is below 65C, the Peltiers operate;
2. When the maximum temperature of Accumulator comes to or exceeds 65C, the Peltiers are cut off.

6.1.4 Results

6.1.4.1 HP TS Switched Case: at 18s

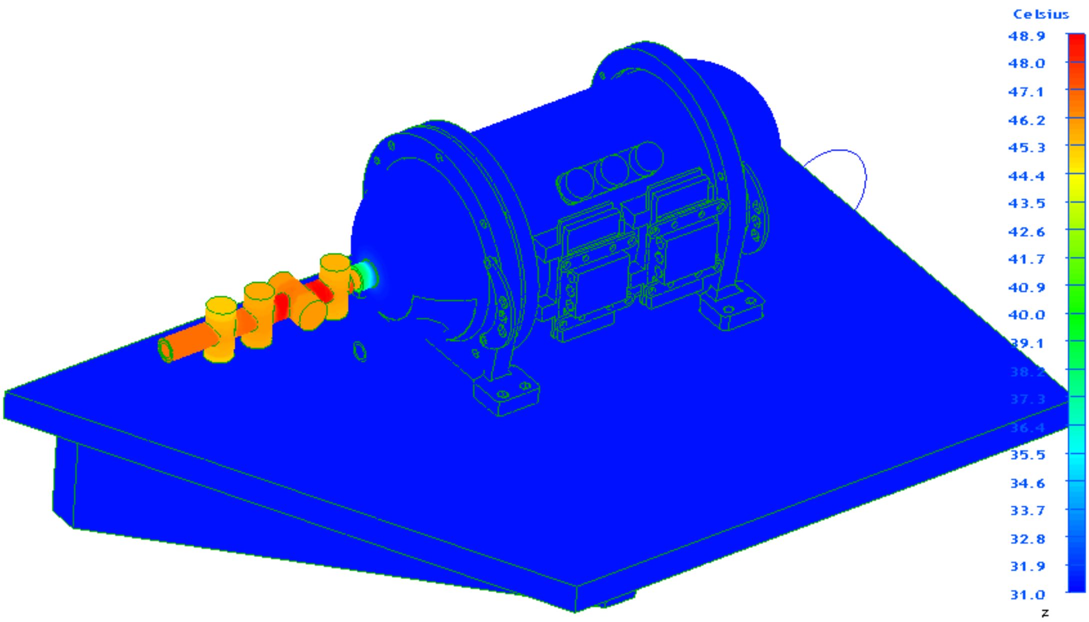


Figure 6-1 Temperature Distribution under load case 1: HP TS Switched

6.1.4.2 Peltier TS Switched Case: at 120s

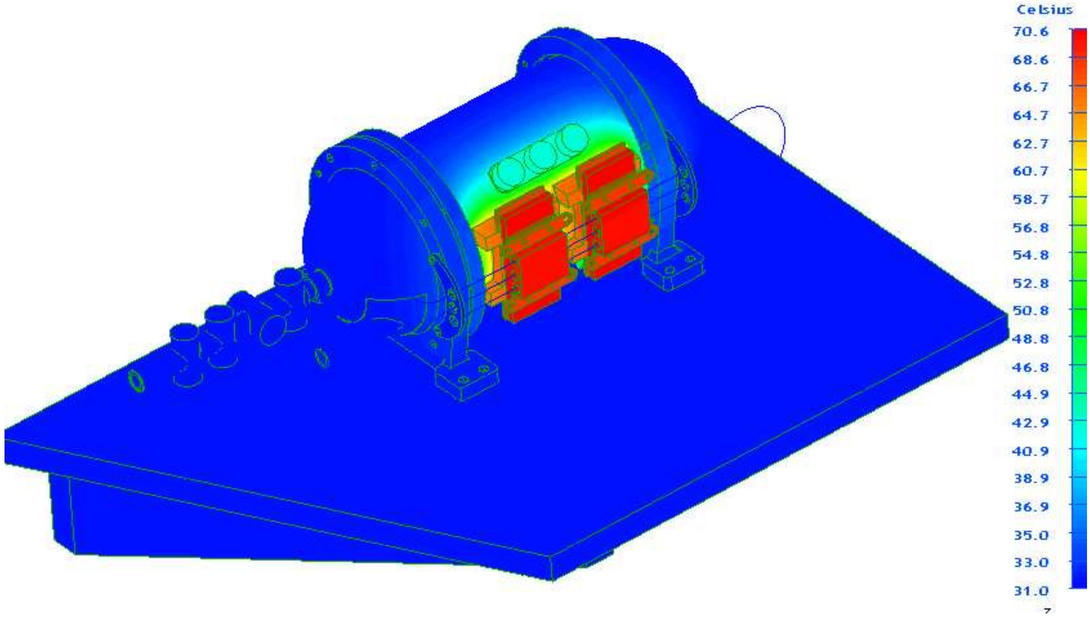


Figure 6-2 Temperature Distribution under load case 2: Peltier TS Switched

6.1.4.3 Combined of 1 and 2

1>Temperature profile when HP-TS switch: 18s

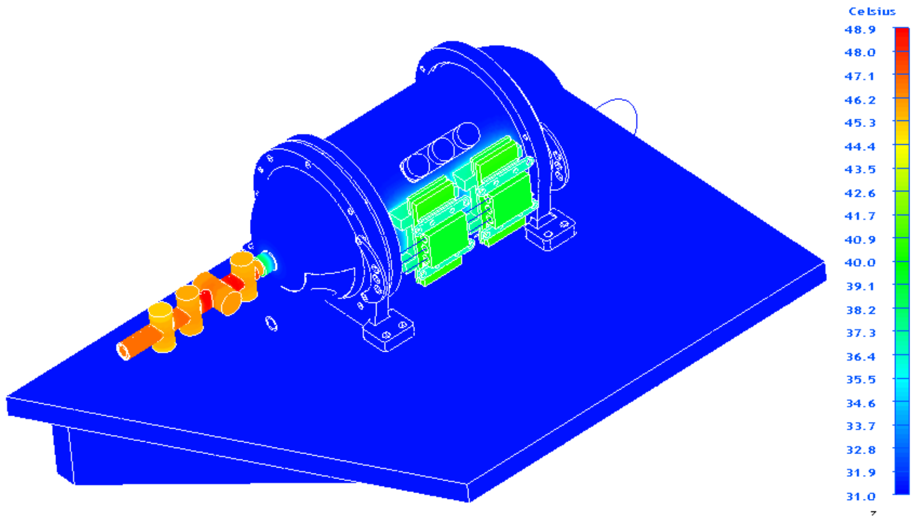


Figure 6-3 Temperature Distribution under load case 3a: HP Max

2>Temperature profile when Peltier-TS switch: 118s

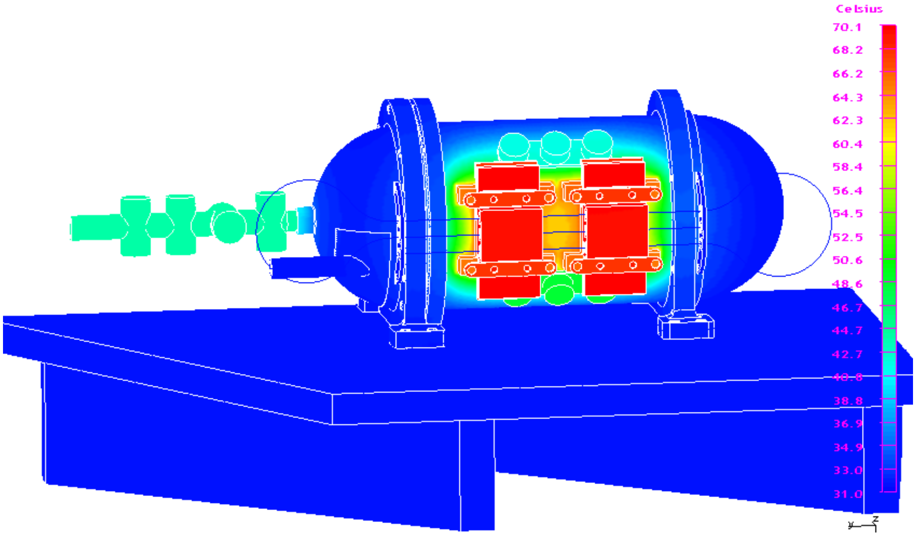


Figure 6-4 Temperature Distribution under load case 3b: Peltier Max

6.2 Static Analysis for in orbit load cases

The Soldering Layer connecting the copper saddle and accumulator has passed through the tensile experiment, so it is not included in the MoS analysis. The Von Mises stress, Max Principal stress and maximum displacement under different load cases of the accumulator assembly is listed in following tables.

Table 6-4 The Restrains at Base plate bolts location

Restraints *at Base Plate Bolts Locations*					
Ux	Uy	Uz	Rx	Ry	Rz
0	0	0	0	0	0

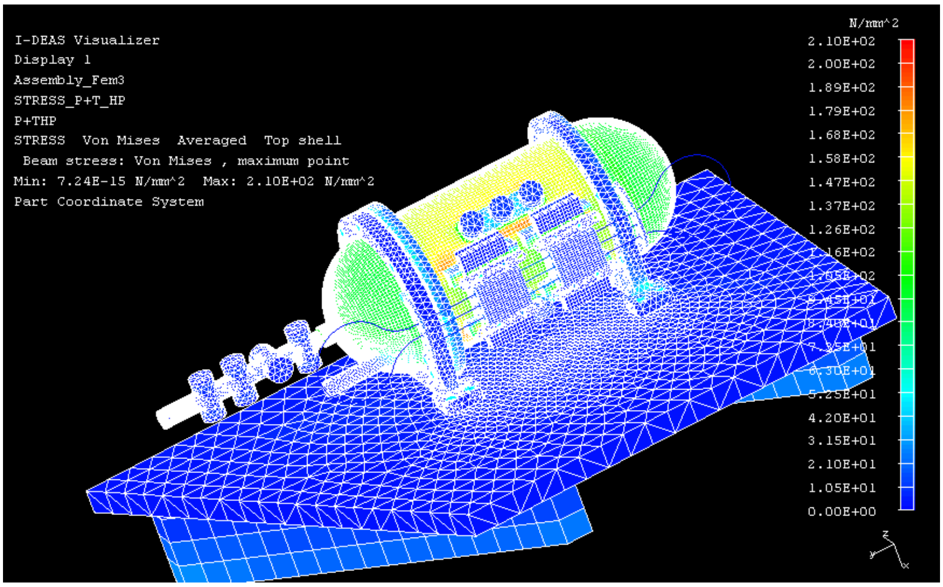


Figure 6-5 Static Analysis: Stress: Pressure & Temperature-HP

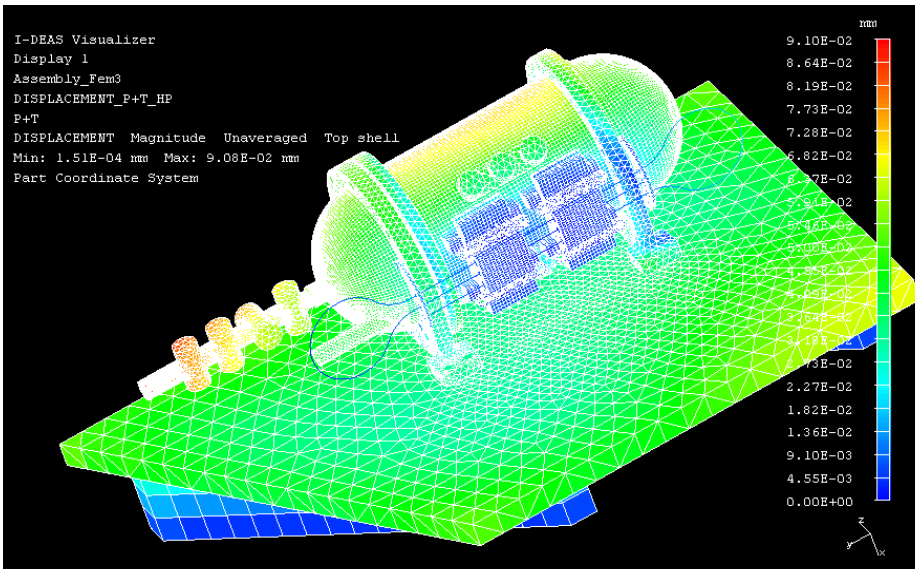


Figure 6-6 Static Analysis: Displacement: Pressure& Temperature-HP

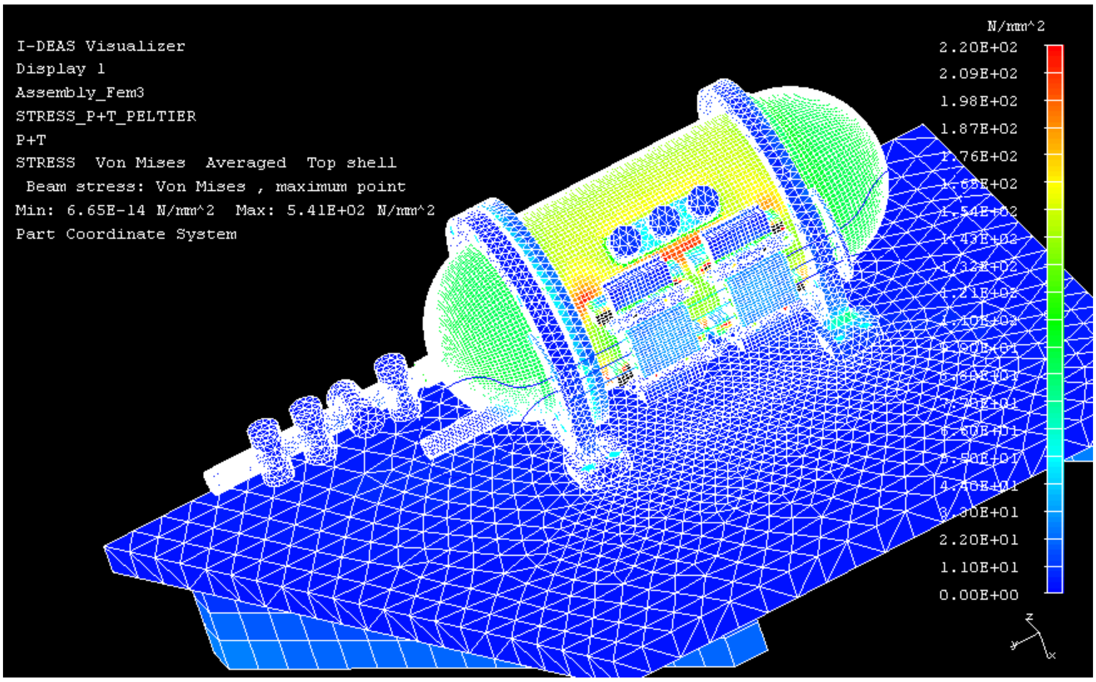


Figure 6-7 Static Analysis: Stress: Pressure& Temperature-Peltitier

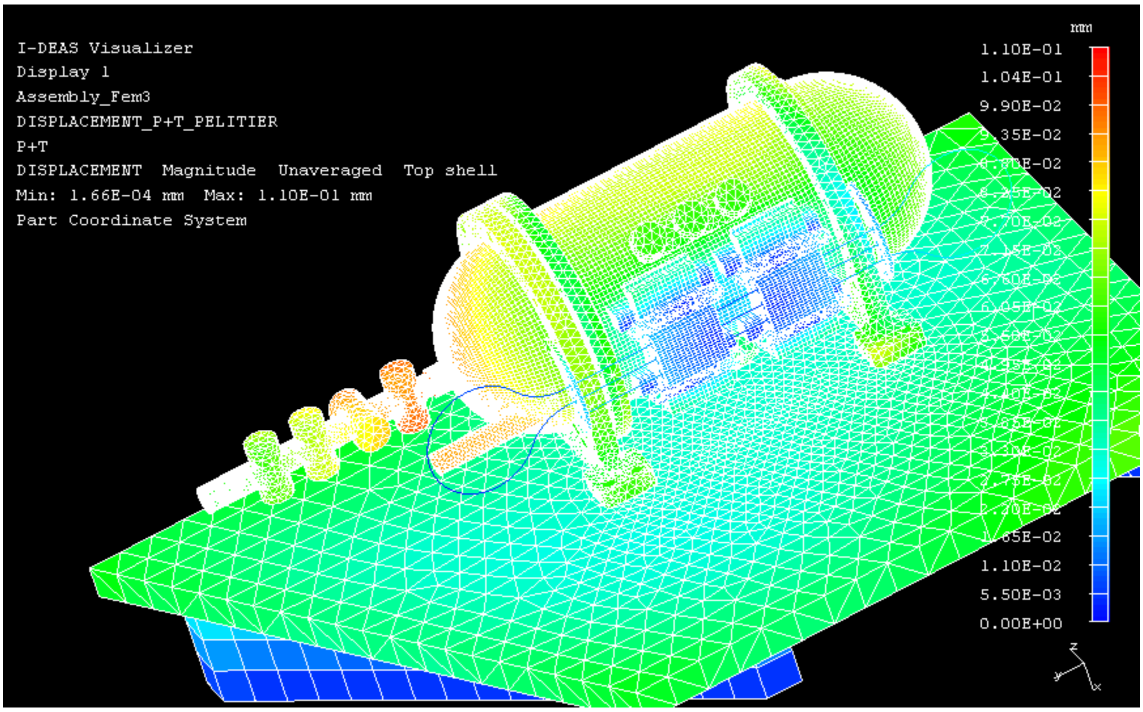


Figure 6-8 Static Analysis: Displacement: Pressure& Temperature-Peltitier

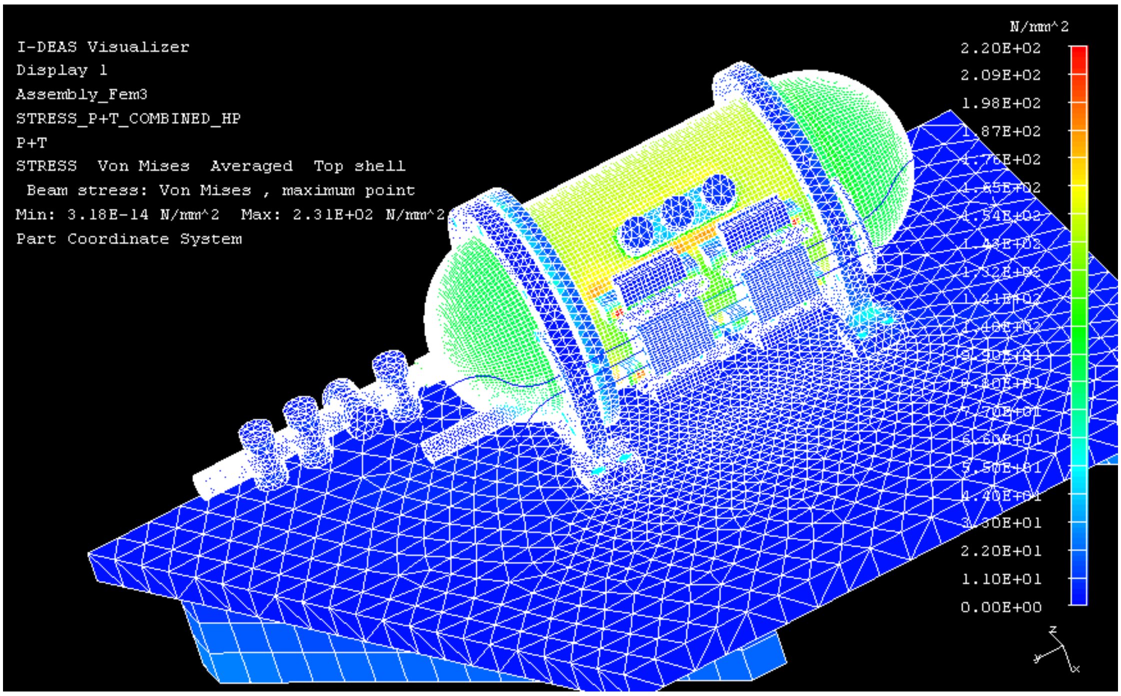


Figure 6-9 Static Analysis: Stress: Pressure& Temperature-Combined-HP

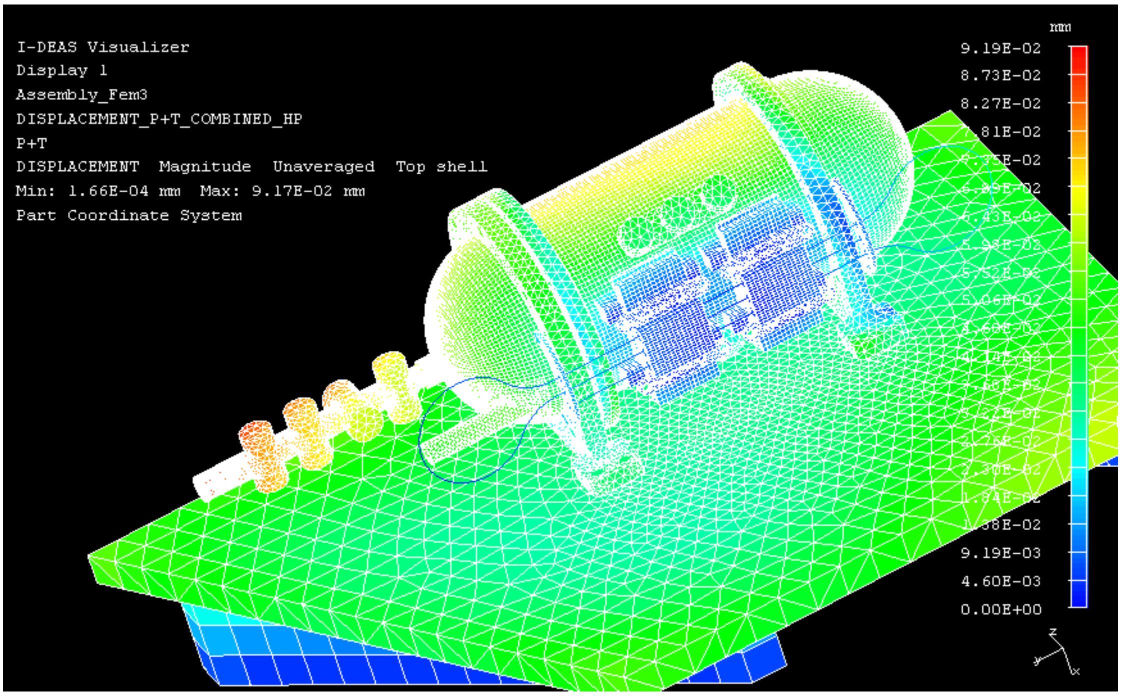


Figure 6-10 Static Analysis: Displacement: Pressure& Temperature-Combined-HP

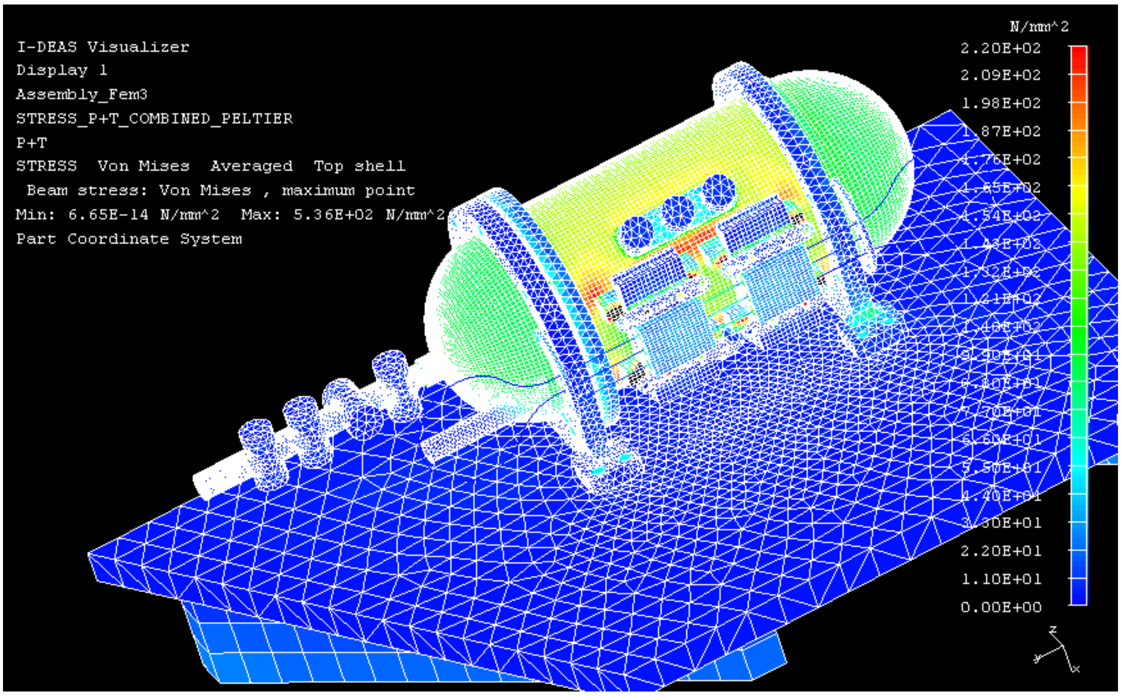


Figure 6-11 Static Analysis: Stress: Pressure& Temperature-Combined-Peltier

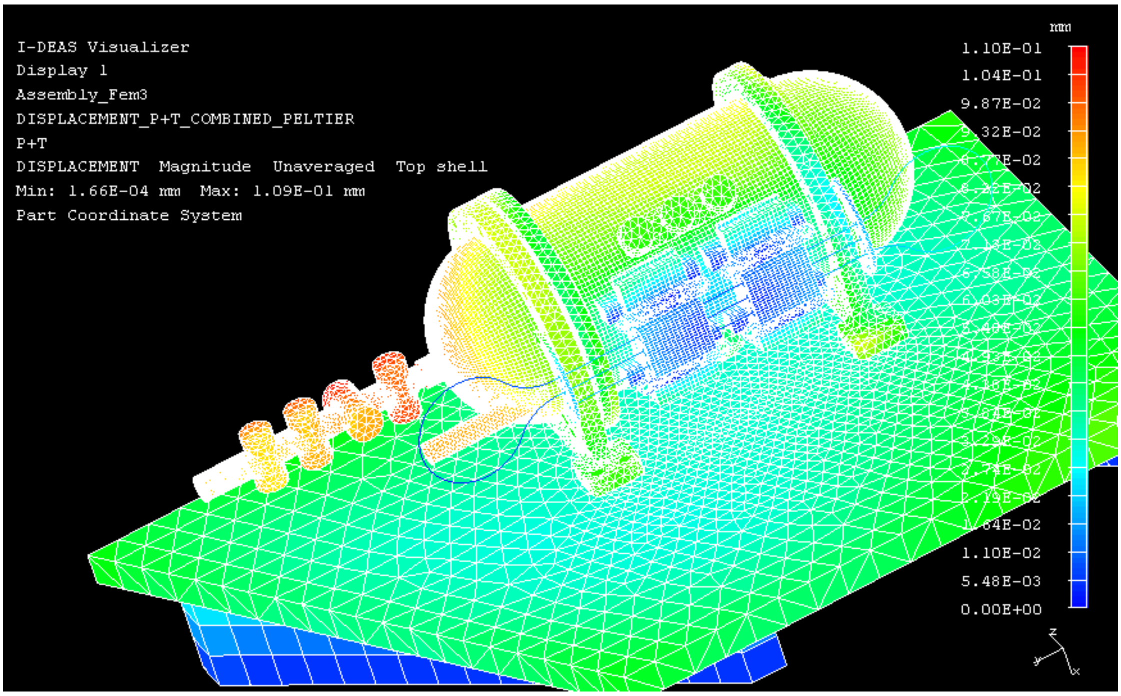


Figure 6-12 Static Analysis: Displacement: Pressure& Temperature-Combined-Peltier

Table 6-5 **Accumulator** Stresses, Displacements and Margin of Safety

<table>
<tr><td colspan="3">Loads Cases</td><td colspan="5">Accumulator ($FS_y = 1.5 \quad FS_{ult} = 2.5$)
Material 316Ln</td></tr>
<tr><td rowspan="2">Load Case</td><td rowspan="2" colspan="2">Case Description</td><td colspan="2">Max Stress [N/mm2]</td><td rowspan="2">Displacement (mm)</td><td colspan="2">Margin of Safety</td></tr>
<tr><td>Von Mises</td><td>Max Principal</td><td>Yield</td><td>Ultimate</td></tr>
<tr><td>1</td><td colspan="2">HP TS switched</td><td>315.0</td><td>562.5</td><td>0.0764</td><td>0.06</td><td>0.16</td></tr>
<tr><td>2</td><td colspan="2">Peltier TS switched</td><td>328.5</td><td>637.5</td><td>0.110</td><td>0.02</td><td>0.02</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Combined 1 and 2</td><td>HP Max</td><td>315.0</td><td>562.5</td><td>0.0809</td><td>0.06</td><td>0.16</td></tr>
<tr><td>Peltier Max</td><td>327.0</td><td>637.5</td><td>0.0109</td><td>0.02</td><td>0.02</td></tr>
</table>

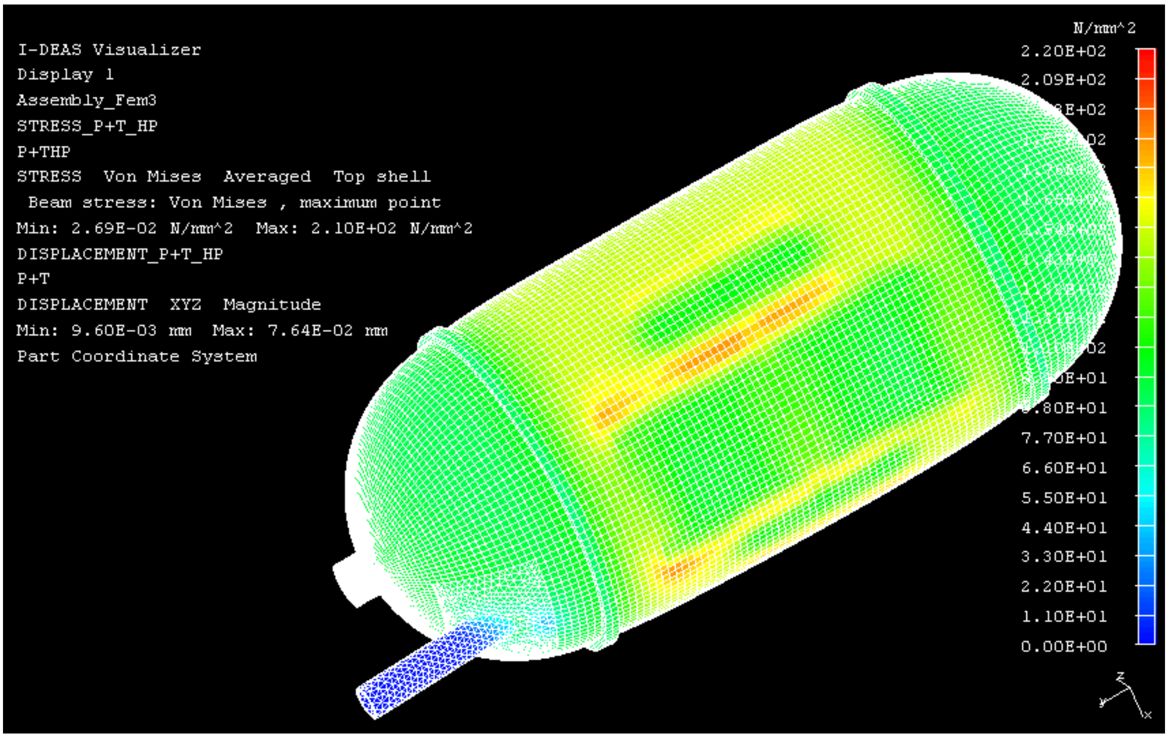


Figure 6-13 Static Analysis: Accumulator Stress: Pressure& Temperature-HP

Table 6-6 Stresses, Displacements and Margin of Safety under different load cases

Loads Cases:		Fixed Bracket_Clamp Collar&Wedge (Fsy=1.25 FSult=2) Material:316L				
Load Case	Case Description	Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
		Von Mises	Max Principal		Yield	Ultimate
1	HP TS switched	114.5	181.4	0.0710	1.10	2.03
2	Peltier TS switched	120.0	195.0	0.106	1.00	1.82
3	Combined 1 and 2 / HP Max	114.4	181.0	0.076	1.10	2.04

		Peltier Max	119.4	193.8	0.105	1.01	1.84

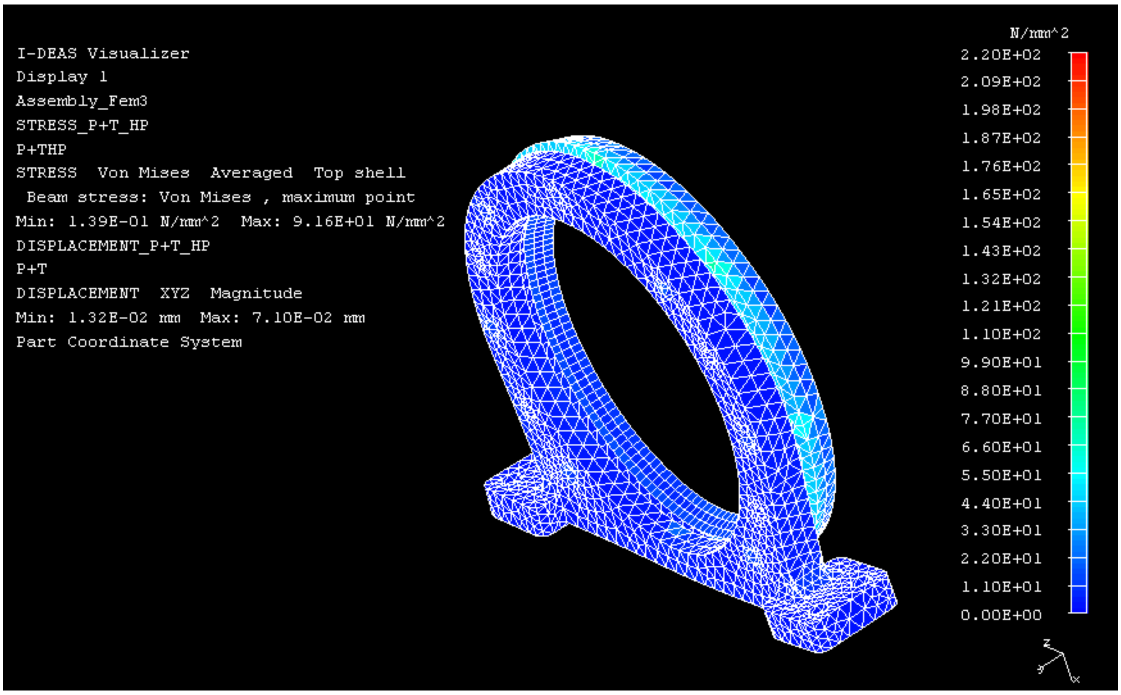


Figure 6-14 Fixed Bracket Clamp Collar&Wedge Stress: Pressure& Temperature-HP

Table 6-7 Slide Brackets Stresses, Displacements and Margin of Safety

Loads Cases:		SIding Bracket (Fsy=1.25 FSult=2) Material:AL7075				
Load Case	Case Description	Max Stress [N/mm2]		Displacement	Margin of Safety	
		Von Mises	Max Principal	(mm)	Yield	Ultimate
1	HP TS switched	74.5	79.2	0.0702	4.28	4.92
2	Peltier TS switched	104.5	118.6	0.0915	2.76	2.95

3	Combined 1 and 2	HP Max	78.4	84.4	0.0720	4.01	4.55
		Peltier Max	104.0	117.8	0.0908	2.78	2.98

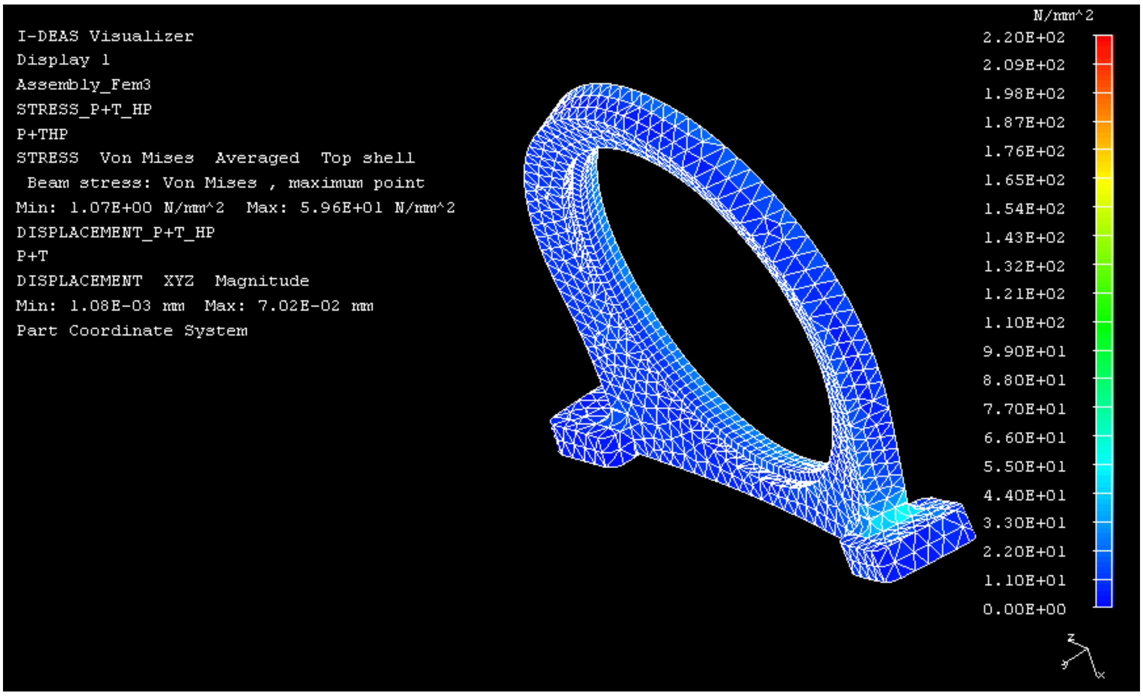


Figure 6-15 Static Analysis: Slding Bracket Stress: Pressure& Temperature-HP

Table 6-8 **Heat Pipe** Stresses, Displacements and Margin of Safety under different load cases

Loads Cases			Heat Pipe (Fsy=1.5 FSult=4) Material 316L				
Load	Case		Max Stress [N/mm2]		Displacement	Margin of	

Case	Description					Safety	
			Von Mises	Max Principal	(mm)	Yield	Ultimate
1	HP TS switched		67.9	125.2	0.0910	2.53	3.39
2	Peltier TS switched		125.1	256.8	0.0103	0.92	1.14
3	Combined 1 and 2	HP Max	70.6	142.4	0.0919	2.40	2.86
		Peltier Max	101.6	246.4	0.110	1.36	1.23

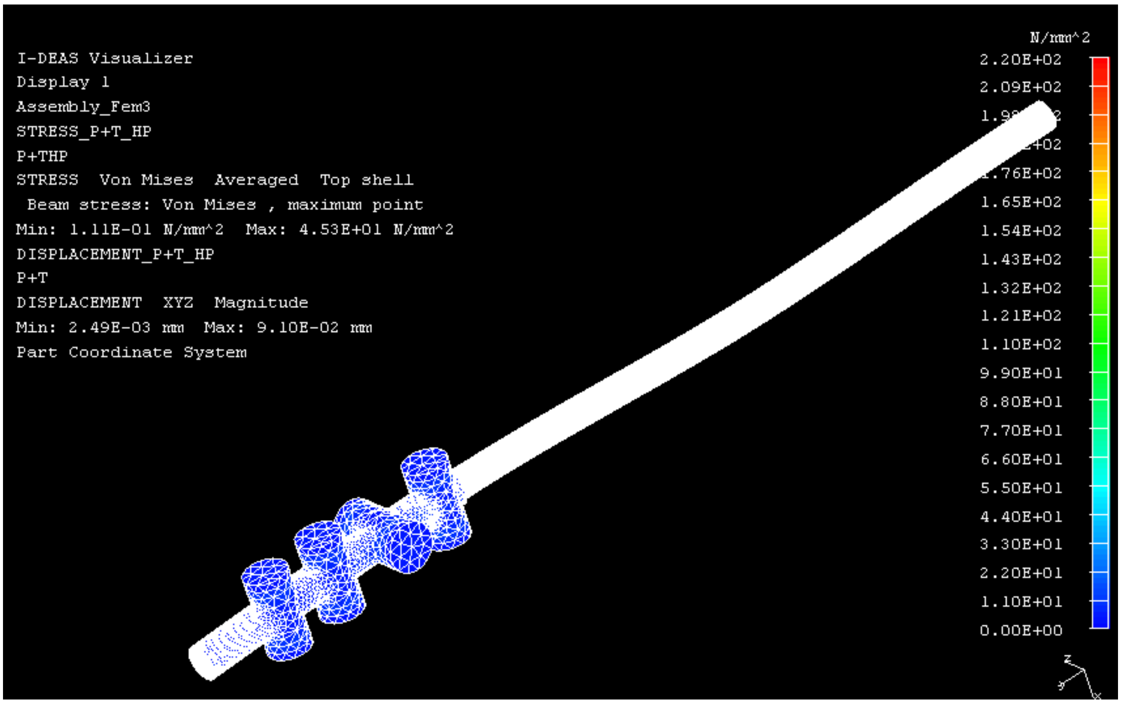


Figure 6-16 Static Analysis: Heat Pipe Stress: Pressure& Temperature-HP

Table 6-9 Peltier Pipe Fix Stresses, Displacements and Margin of Safety

Loads Cases:			Peltier Pipe Fixed (Fsy=1.25 FSult=2) Material:316L				
Load Case	Case Description		Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
			Von Mises	Max Principal		Yield	Ultimate
1	HP TS switched		71.4	100.2	0.0225	2.36	4.49
2	Peltier TS switched		158.8	250.0	0.0721	0.51	1.20
3	Combined 1 and 2	HP Max	78.6	119.2	0.0256	2.05	3.61
		Peltier Max	157.5	248.0	0.0717	0.52	1.22

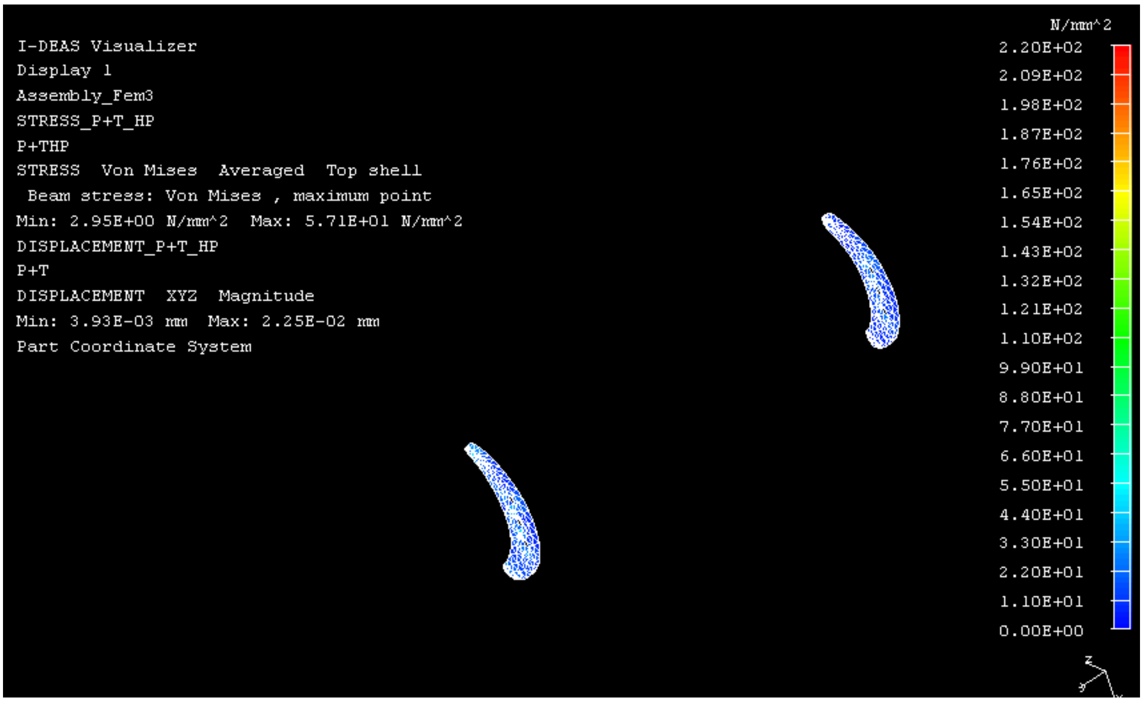


Figure 6-17 Static Analysis: Peltier Pipe Fixed Stress: Pressure& Temperature-HP

Table 6-10 Stresses, Displacements and Margin of Safety under different load cases

Loads Cases:		Peltier Heat Exchanger & Spring Support (Fsy=1.25 FSult=2) Material:316L				
Load Case	Case Description	Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
		Von Mises	Max Principal		Yield	Ultimate
1	HP TS switched	29.6	28.6	0.0096	7.10	18.23
2	Peltier TS switched	167.5	129.4	0.0466	0.43	3.25
3	Combined 1 and 2 HP Max	58.7	41.2	0.0182	3.09	12.35

		Peltier Max	165.0	91.0	0.0461	0.45	5.04

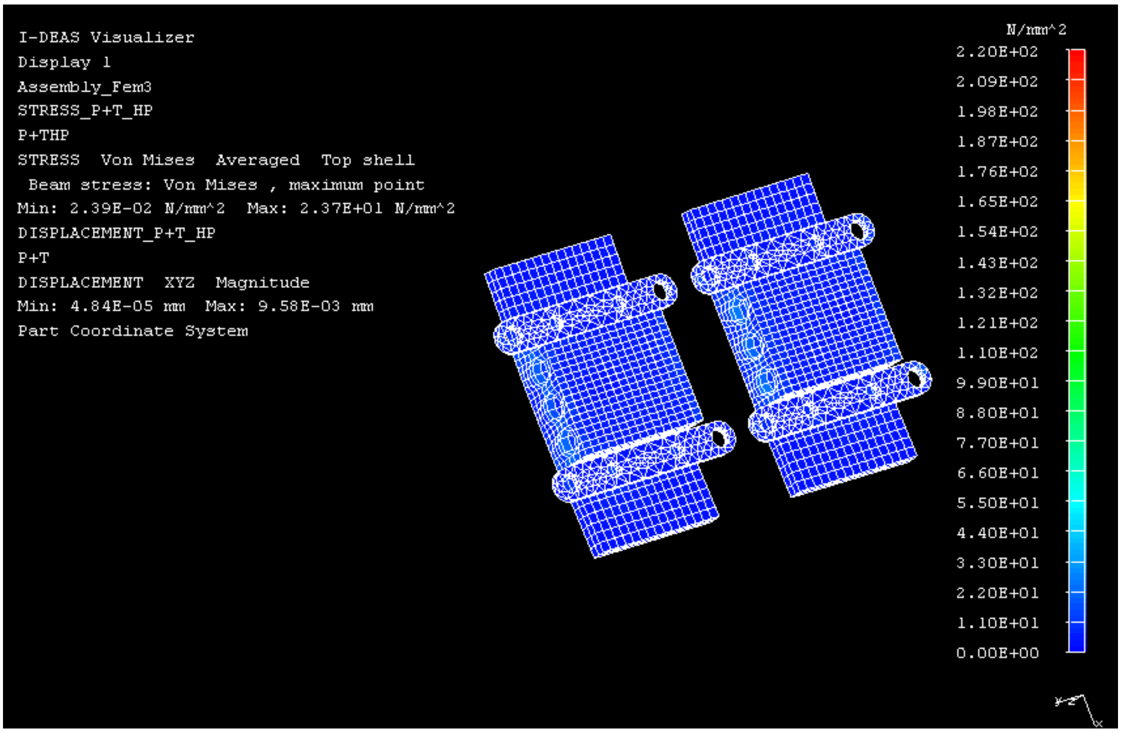


Figure 6-18 Static Analysis: Peltier Heat Exchanger & Spring Support Stress: Pressure& Temperature-HP

Table 6-11 Stresses, Displacements and Margin of Safety under different load cases

Loads Cases:		TS &Peltier heat exchanger press (Fsy=1.25 FSult=2) Material: 316L				
Load Case	Case Description	Max Stress [N/mm2]		Displacement (mm)	Margin of Safety	
		Von Mises	Max Principal		Yield	Ultimate

1	HP TS switched		142.5	248	0.0504	0.68	1.22
2	Peltier TS switched		97.5	302.0	0.0679	1.46	0.82
3	Combined 1 and 2	HP Max	101.3	256.0	0.0516	1.37	1.15
		Peltier Max	96.3	302.0	0.0675	1.49	0.82

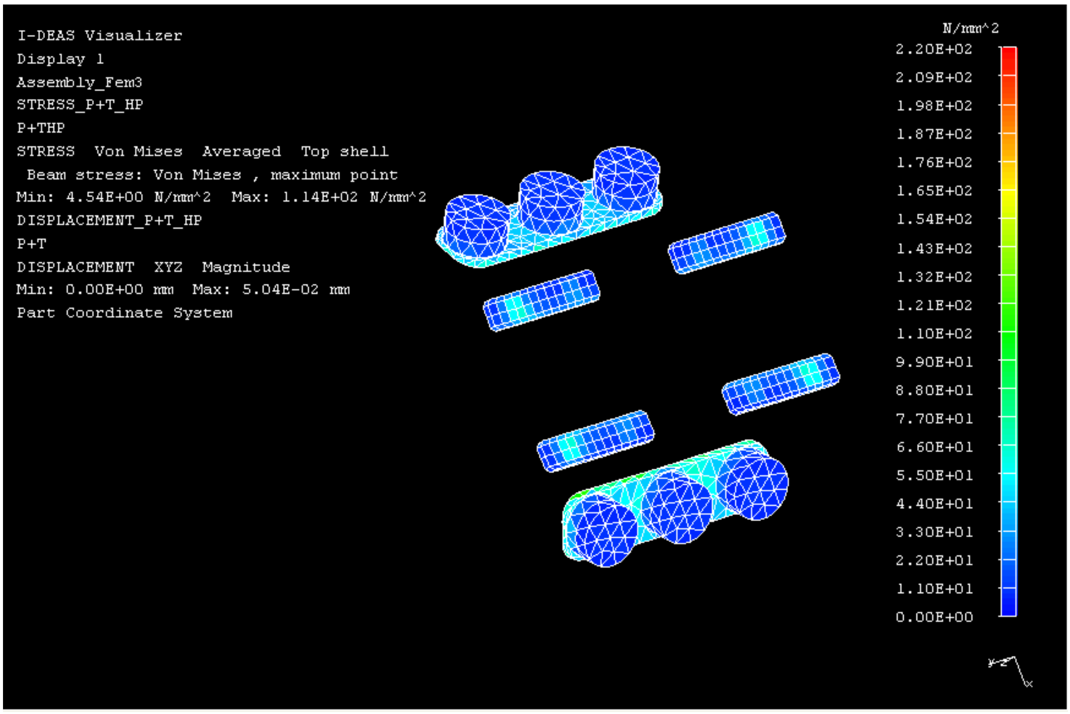


Figure 6-19 Static Analysis: TS &Peltier heat exchanger press Stress: Pressure& Temperature-HP

Table 6-12 Accu.Bracket Clamp&Collar Bolt Element Force and MoS Calculation

(Preload:65%)

Accu.Bracket Clamp&Collar Bolt element force and MofSafety Calculation									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
P+T_HP	-11.1	22.8	-32	33.9	7.57	22.8	5.09	2.6	0.12
P+T_Peltier	-41.5	-104	-22.4	47	10.5	104	23.2	6.2	0.09
P+T_Combined_HP_Max	-11.8	17	-34.9	36.8	8.21	17	3.79	2.6	0.12
P+T_Combined_Peltier Max	-15.5	-16.2	-51.3	53.6	12.0	16.2	3.62	3.4	0.12

Table 6-13 PipeFix&Clamp Bolt Element Force and MoS Calculation(Preload: 65%)

PipeFix&Clamp Bolt element force and MofSafety Calculation									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
P+T_HP	37	15.9	-5.89	37.5	8.37	15.9	3.55	0	0.124
P+T_Peltier	27.8	-36.4	9.29	29.3	6.54	36.4	8.13	0	0.122
P+T_Combined_HP_Max	34.6	-10.3	1.73	34.6	7.72	10.3	2.30	0	0.124
P+T_Combined_Peltier Max	57	-44.6	8.99	57.7	12.88	44.6	9.96	0	0.122

Table 6-14 Press&Saddle Bolt Contraint Force and MoS Calculation(Preload: 65%)

Press&Saddle **Bolt Contraint** ***force and MofSafety Calculation***									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
P+T_HP	130	242	171	275	61.38	171	38.17	0	0.107
P+T_Peltier	342	806	189	876	195.54	189	42.19	0	0.106
P+T_Combined_HP_Max	165	330	170	370	82.59	170	37.95	0	0.107
P+T_Combined_Peltier Max	345	796	186	868	193.75	186	41.52	0	0.107

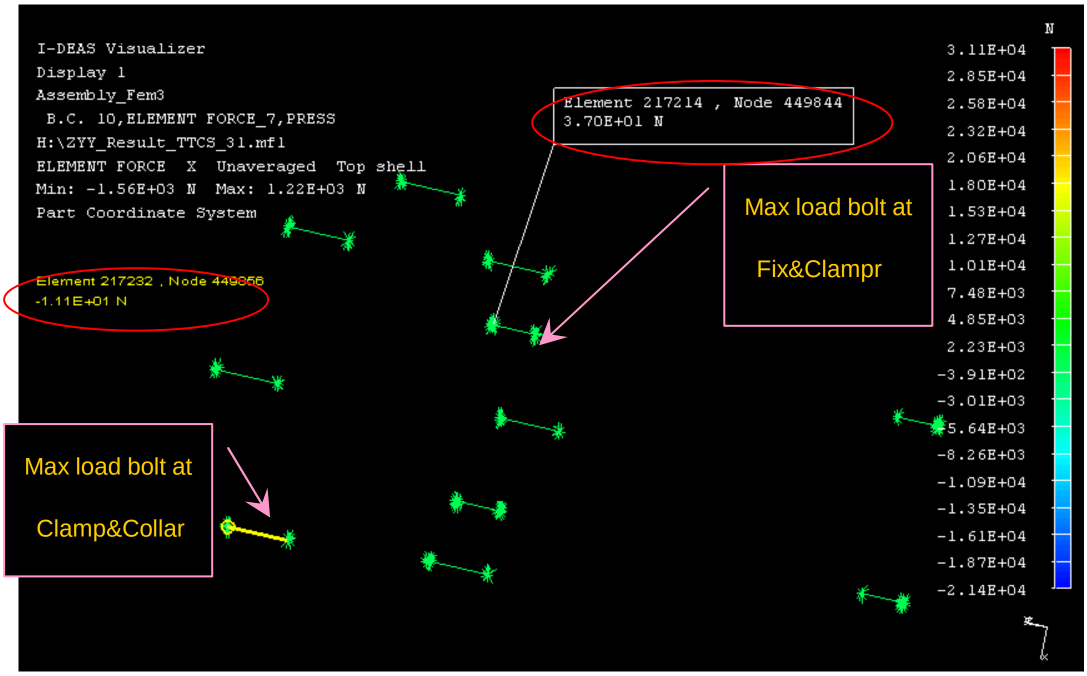


Figure 6-20 Clamp&Collar/ Fix&Clamp element X-Direction forces ; Load case: P+T_HP

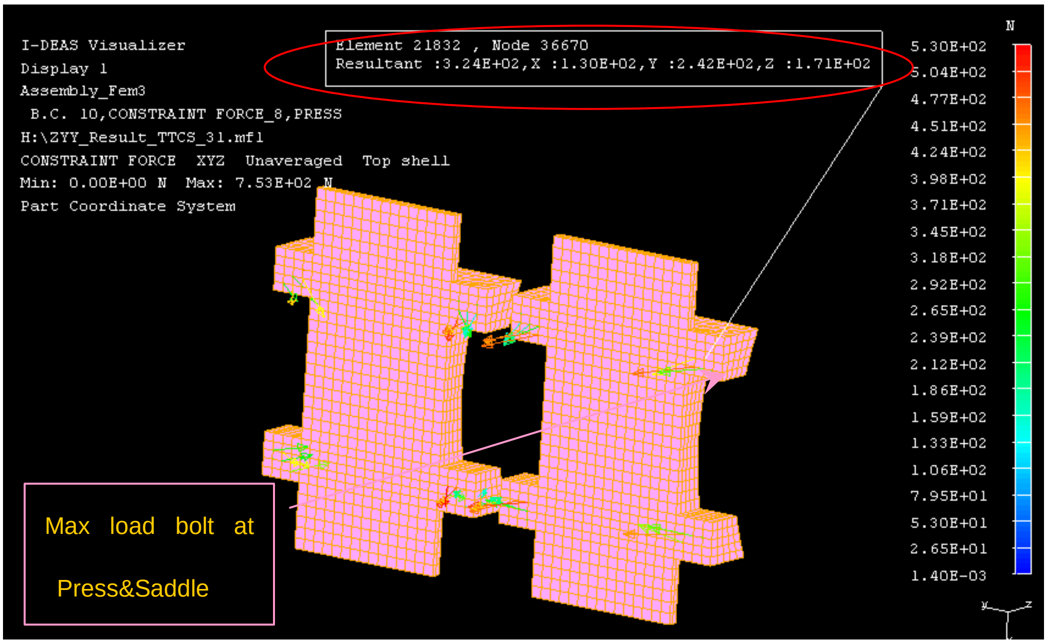


Figure 6-21 Peltier Saddle constraint forces at Bolts location; Load case: P+T_HP

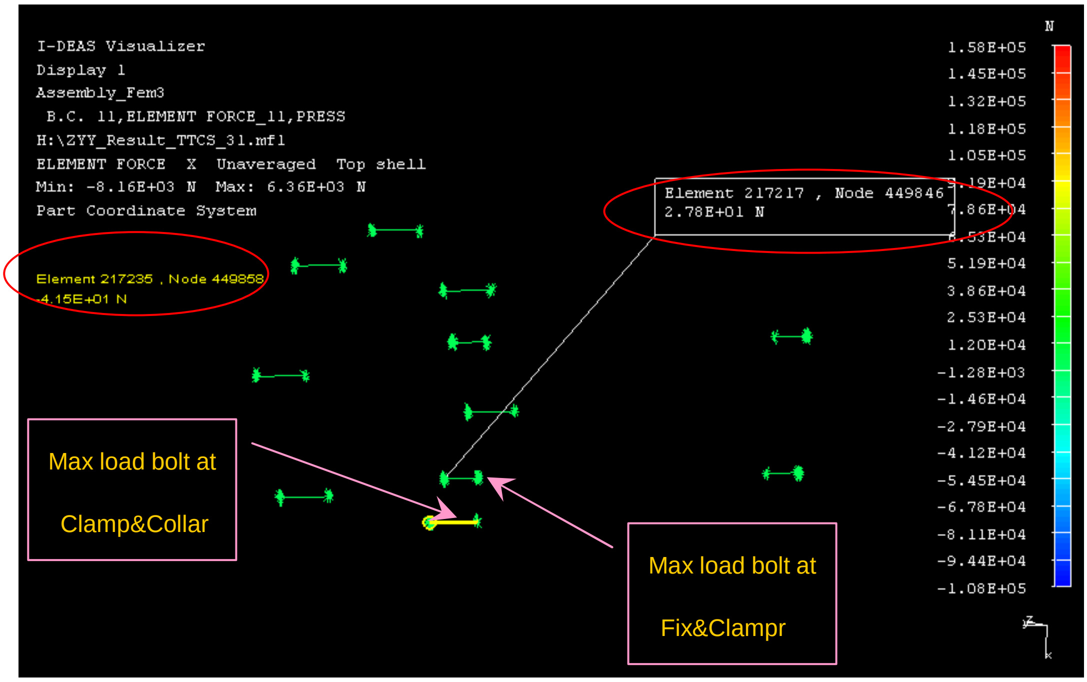


Figure 6-22 Clamp&Collar/ Fix&Clamp element X-Direction forces;

Load case: P+T_ Peltier

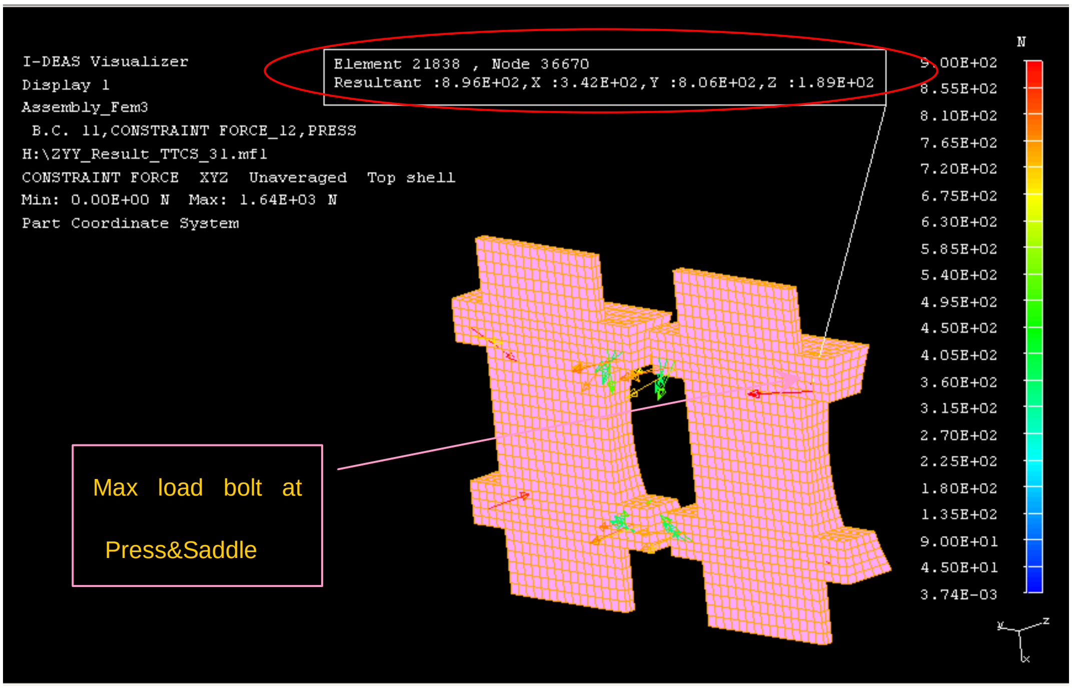


Figure 6-23 Peltier Saddle constraint forces at Bolts location; Load case: P+T_ Peltier

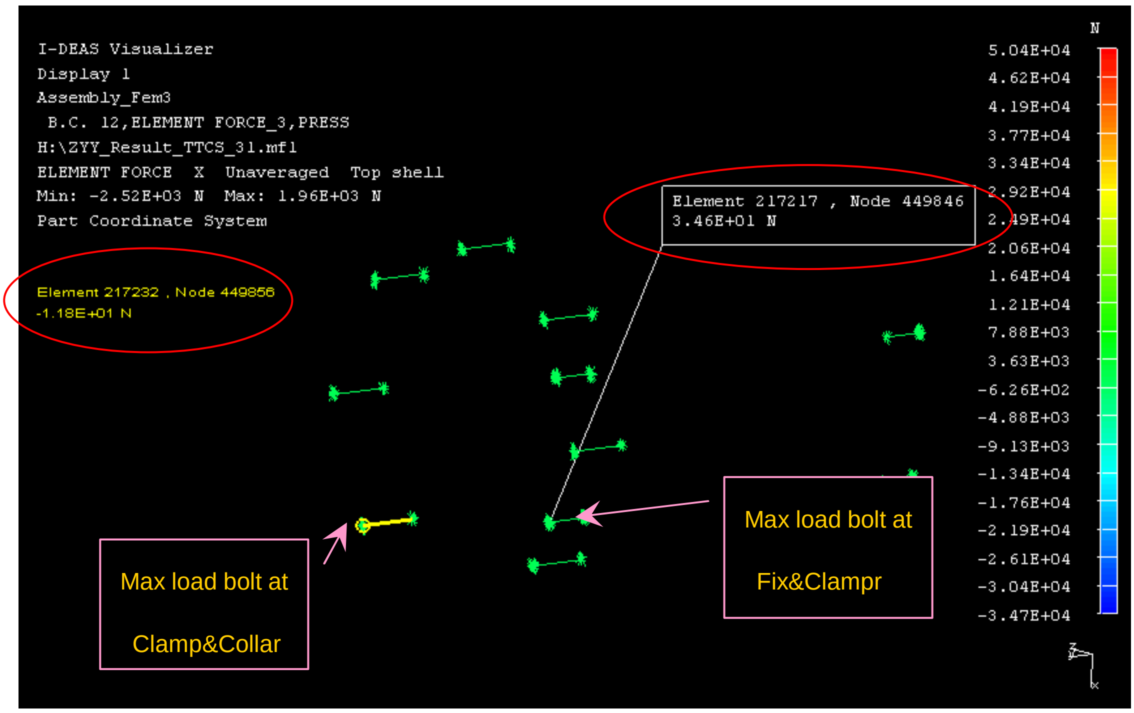


Figure 6-24 Clamp&Collar/ Fix&Clamp element X-Direction forces;

Load case: P+T_Combined_HP_Max r

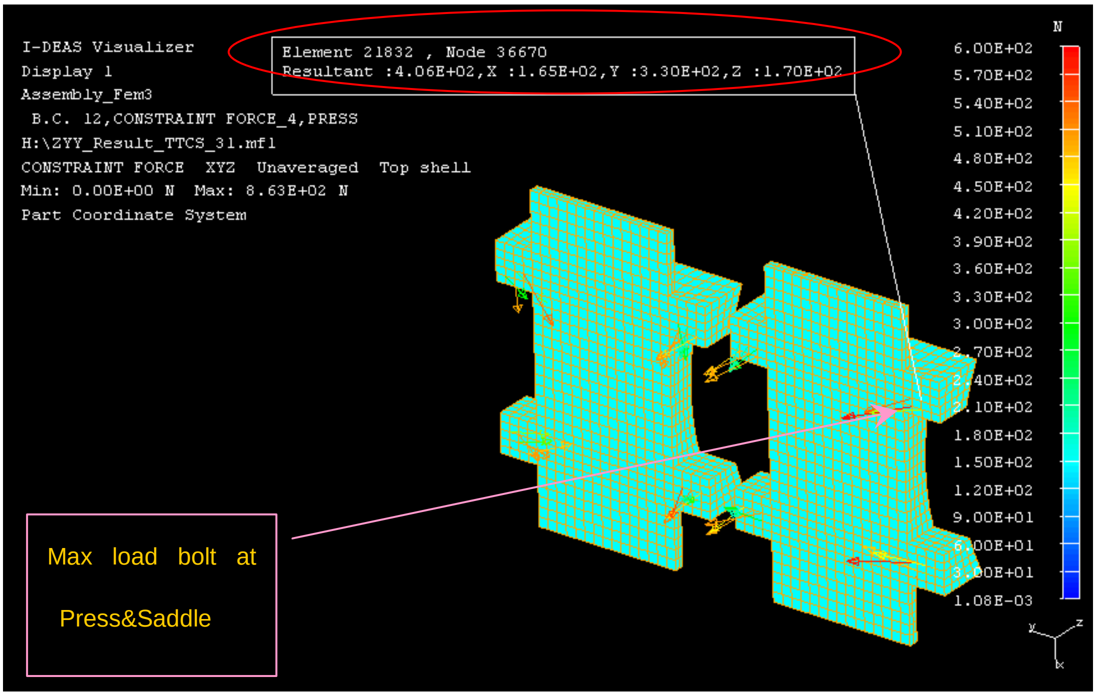
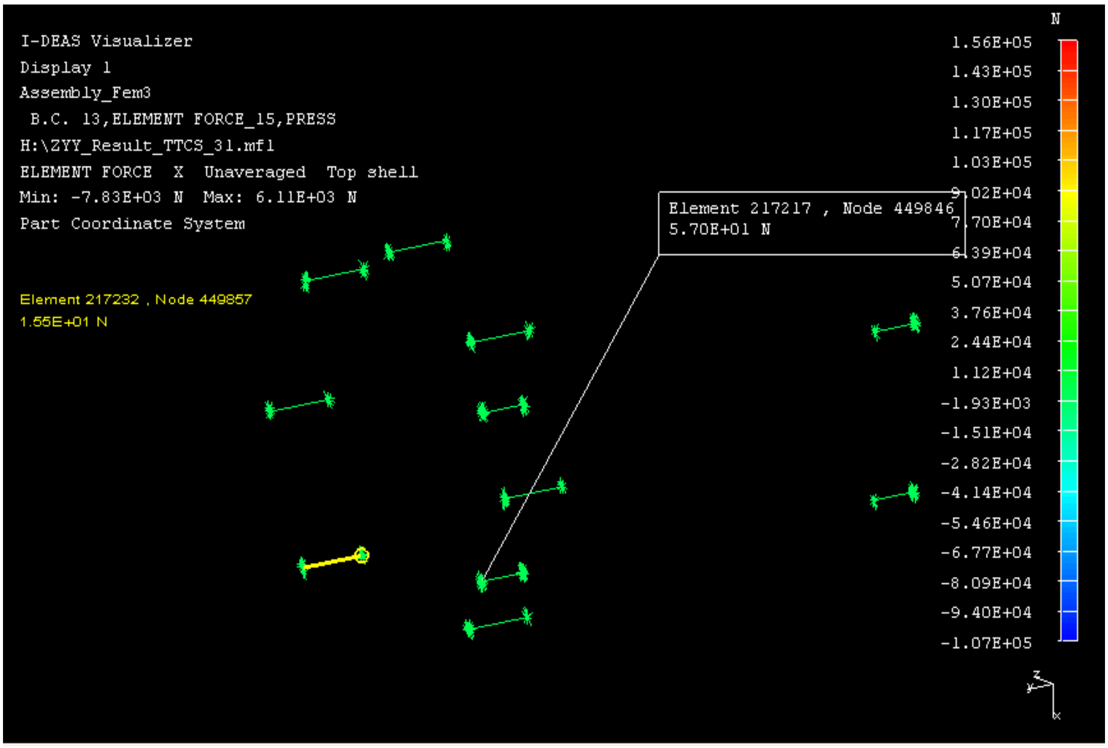


Figure 6-25 Peltier Saddle constraint forces at Bolts location;

Load case: P+T_Combined_HP_Max



Max load bolt at Clamp&Collar

Max load bolt at Fix&Clamp

Figure 6-26 Clamp&Collar/ Fix&Clamp element X-Direction forces;

Load case: P+T_Combined_Peltier Max

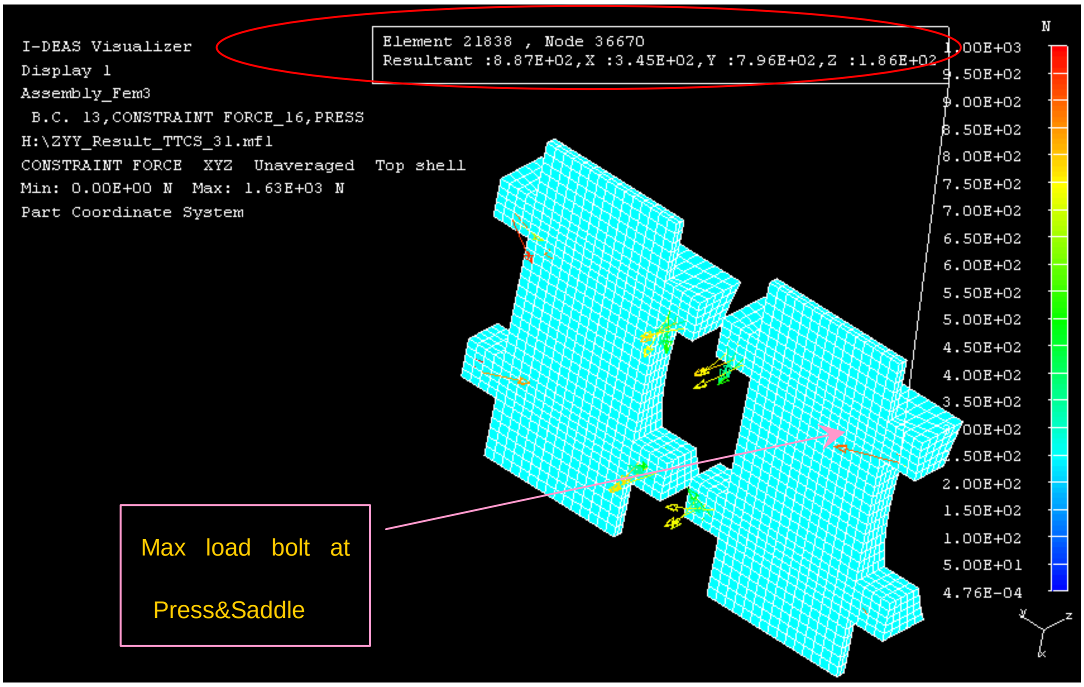


Figure 6-27 Peltier Saddle constraint forces at Bolts location;

Load case: P+T_Combined_Peltier Max

6.3 Fail-Safe Analysis for in orbit load cases

A Fail-Safe analysis was performed with the highest loaded fastener removed and all Margin of Safety are recalculated. The Factor of Safety used for fail-safe analysis is 1.0 for both yield and ultimate.

6.3.1 Location of Removed bolt's.

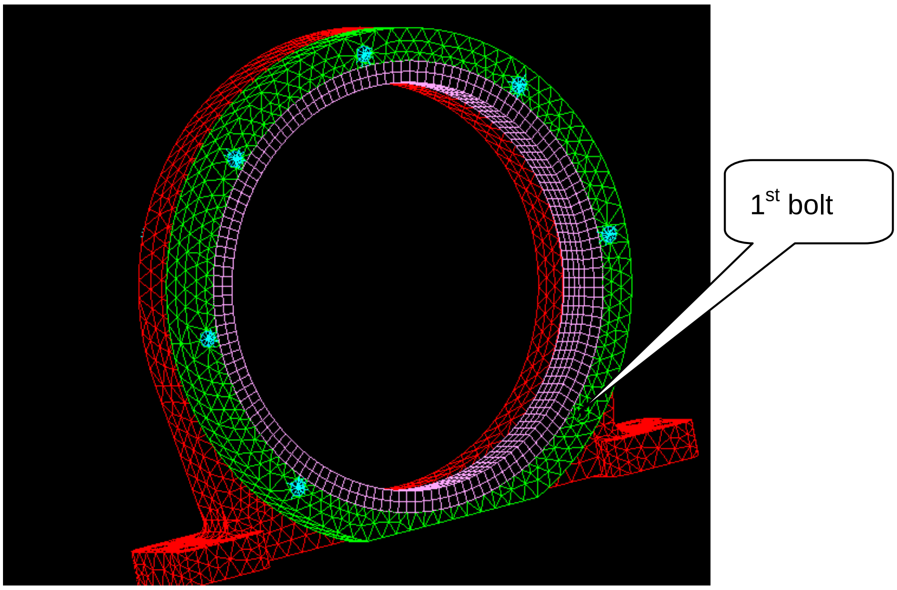


Figure 6-28 Removed 1st bolt

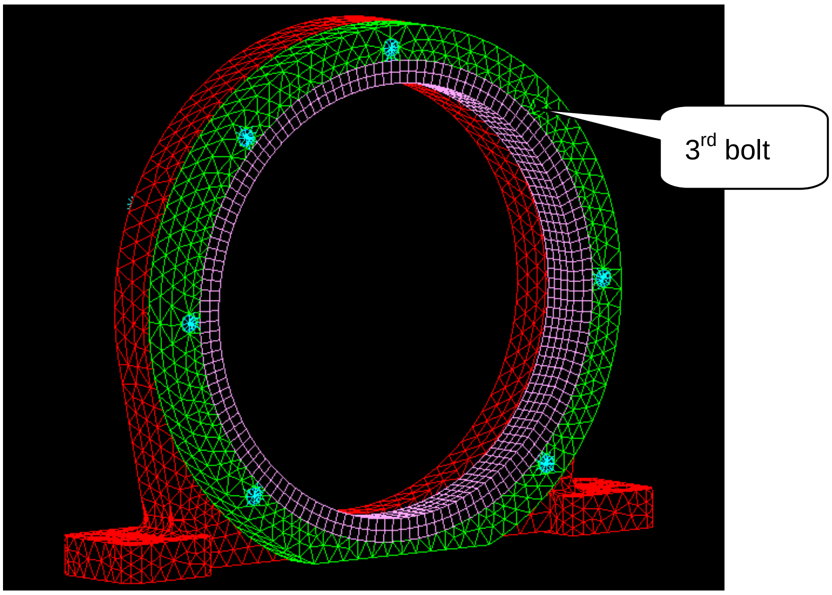


Figure 6-29 Removed 3rd bolt

Table 6-15 Bolts removed details

Fail-Safe Analysis				
Load Case	Case Description		***Removed Bolts***	
			Part	***Bolt Number***
1	HP TS switched		Clamp Assembly	1
2	Peltier TS switched		Clamp Assembly	3
3	Combined 1 and 2	HP Max	Clamp Assembly	1
		Peltier Max	Clamp Assembly	3

The limit Von Mises stress, limit Max Principal stress and maximum displacement under different load cases of the accumulator assembly are listed from Table 6-16 to Table 6-25

Restraints *at Base Plate Bolts Locations*					
Ux	Uy	Uz	Rx	Ry	Rz
0	0	0	0	0	0

6.3.2 Fail safe Stress: under Pressure and Temperature cases, after removed bolt.

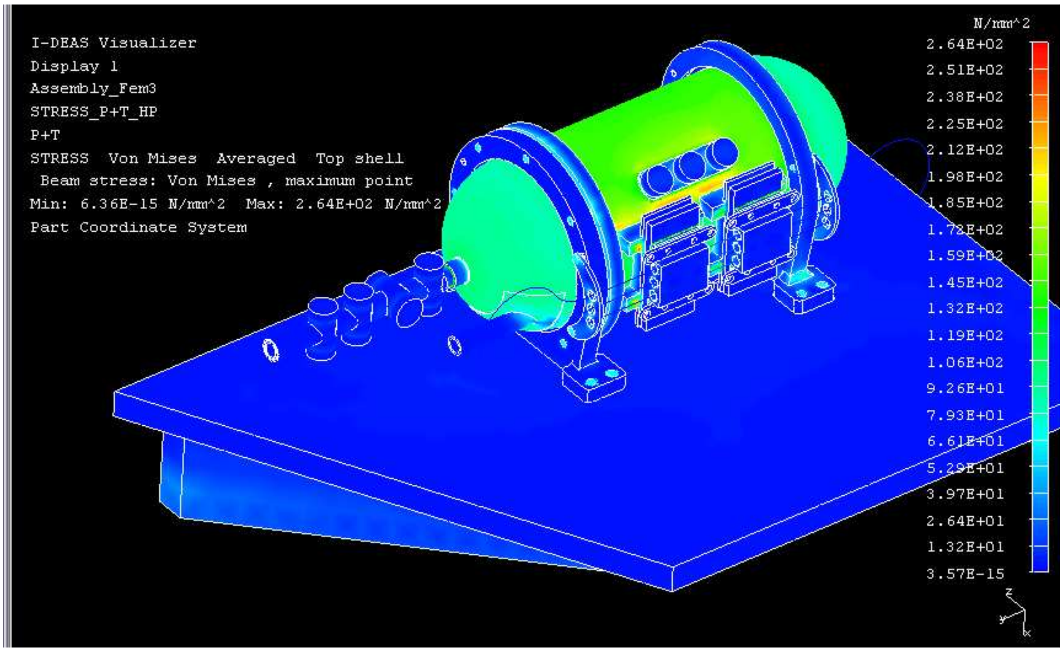


Figure 6-30 Fail-safe Analysis: Removed 1st bolt-Stress: P+ Temperature-HP

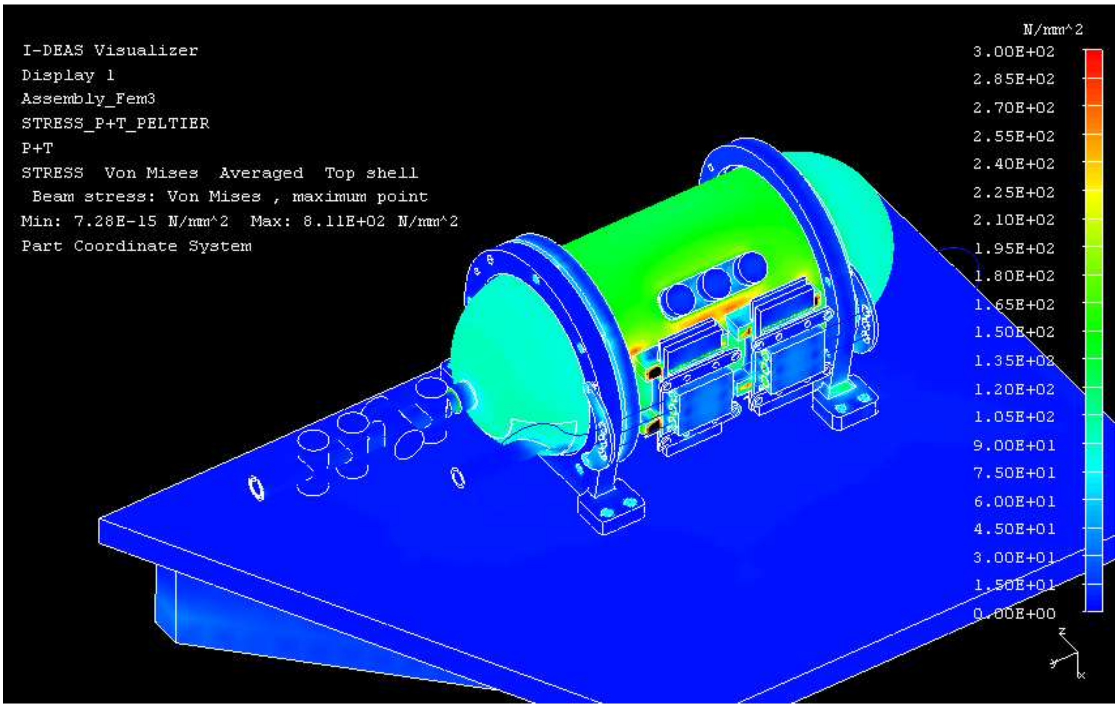


Figure 6-31 Fail-safe Analysis: Removed 3rd bolt-Stress: P+ Temperature-Peltier

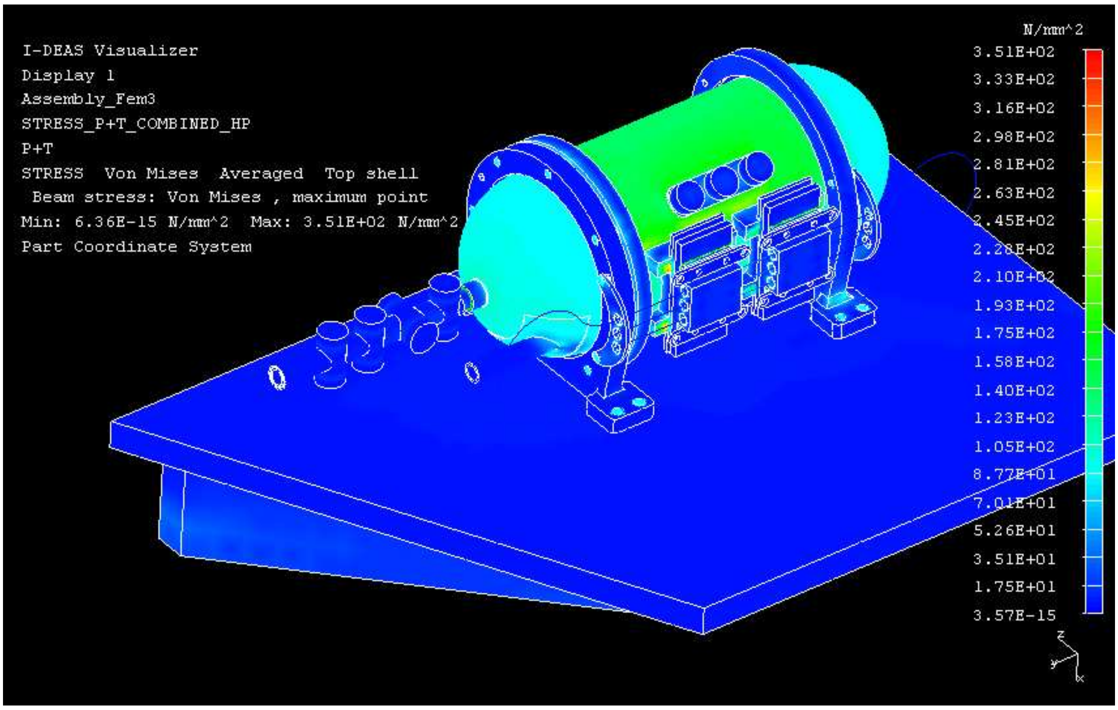


Figure 6-32 Fail-safe Analysis: Removed 1st bolt-Stress: P+ Temperature-Combined HP MAX

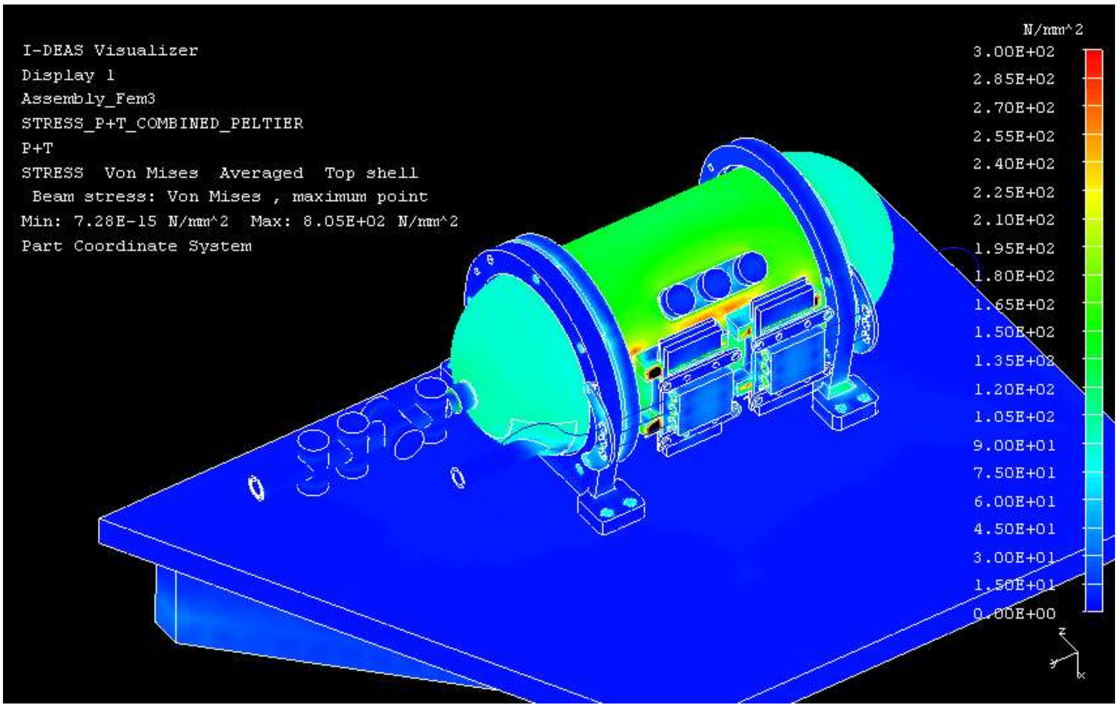


Figure 6-33 Fail-safe Analysis: Removed 3rd bolt-Stress:

P+ Temperature-Combined Peltier MAX

6.3.3 Fail safe Displacement: under Pressure and Temperature cases, after removed bolt.

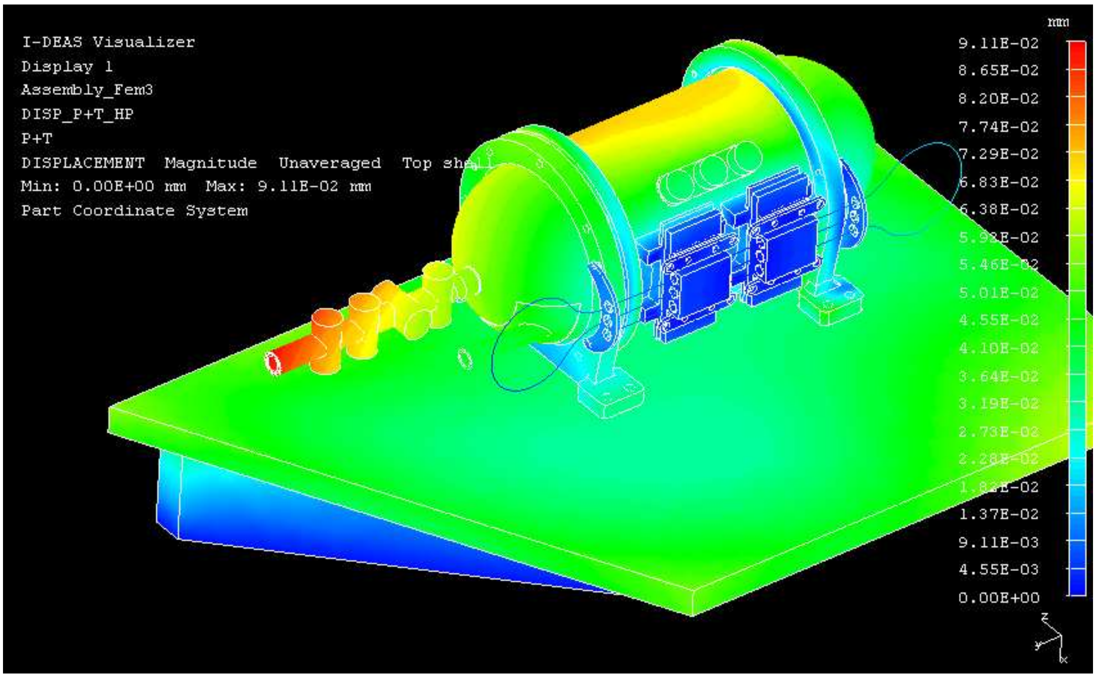


Figure 6-34 Fail-safe Analysis: Removed 1st bolt-Displacement: P+ Temperature HP

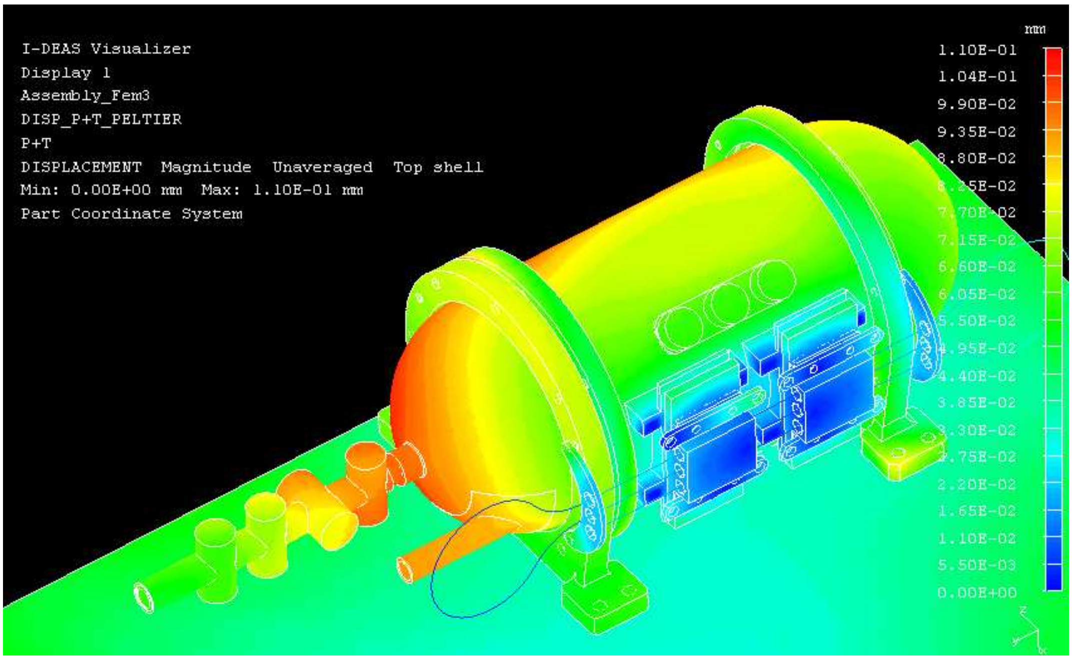


Figure 6-35 Fail-safe Analysis: Removed 3rd bolt-Displacement: P+ Temperature Peltier

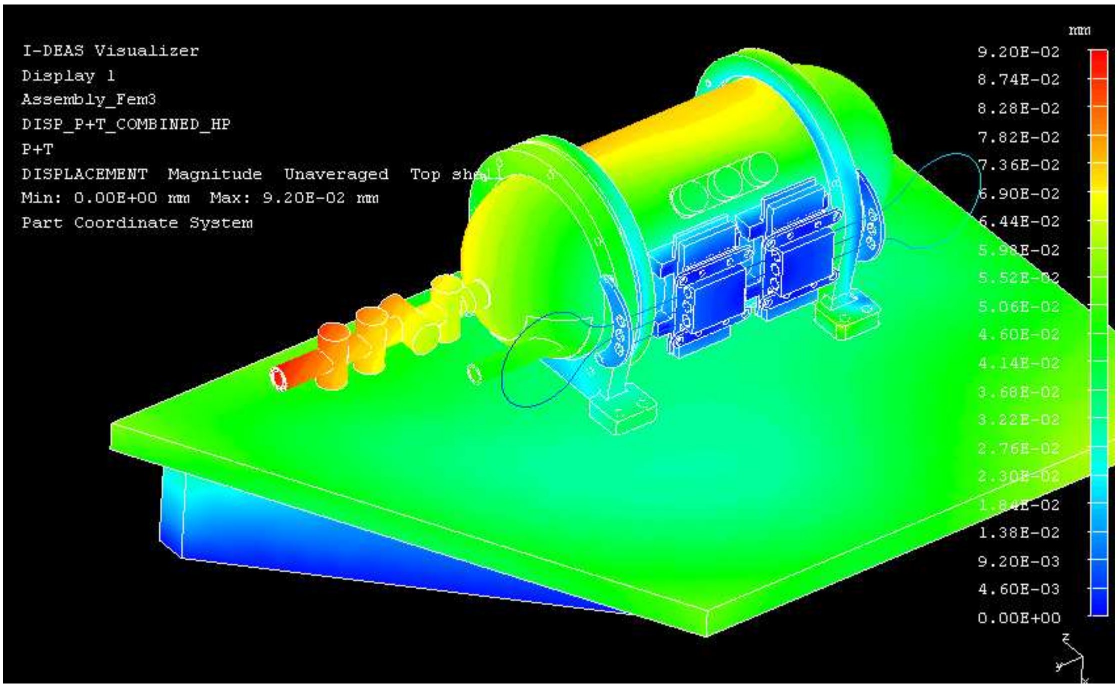


Figure 6-36 Fail-safe Analysis: Removed 1st bolt-Displacement: P+ Temperature Combined HP MAX

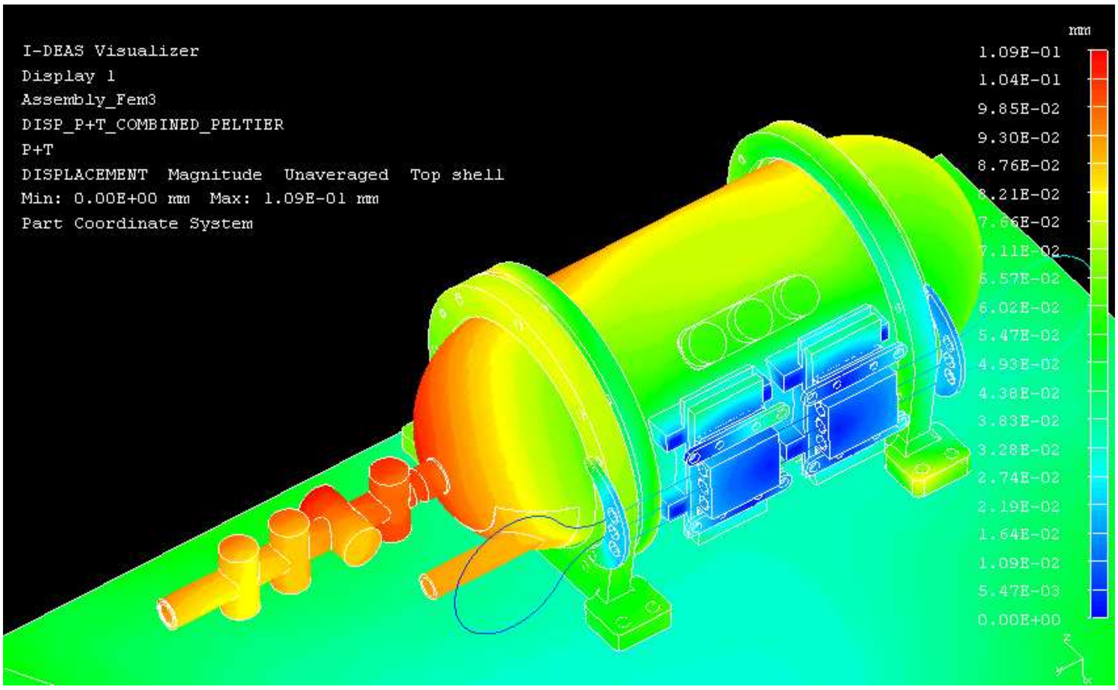


Figure 6-37 Fail-safe Analysis: Removed 3rd bolt-Displacement: P+ Temperature Combined Peltier MAX

6.3.4 Fail safe Result: Load Combination of Pressure and Temperature.

Table 6-16 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

<table>
<tr><th colspan="9">FAIL SAFE ANALYSIS</th></tr>
<tr><th colspan="3">Loads Cases</th><th colspan="6">Accumulator Material 316Ln</th></tr>
<tr><th rowspan="2">Load Case</th><th colspan="2" rowspan="2">Case Description</th><th colspan="2">Max Stress [N/mm2]</th><th>Displacement</th><th colspan="2">Margin of Safety</th></tr>
<tr><th>Von Mises</th><th>Max Principal</th><th>(mm)</th><th>Yield</th><th>Ultimate</th></tr>
<tr><td>1</td><td colspan="2">HP TS switched</td><td>210</td><td>225</td><td>0.0754</td><td>0.60</td><td>1.89</td></tr>
<tr><td>2</td><td colspan="2">Peltier TS switched</td><td>219</td><td>255</td><td>0.1101</td><td>0.53</td><td>1.55</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Combined 1 and 2</td><td>HP Max</td><td>210</td><td>225</td><td>0.0798</td><td>0.60</td><td>1.89</td></tr>
<tr><td>Peltier Max</td><td>217</td><td>255</td><td>0.1091</td><td>0.54</td><td>1.55</td></tr>
</table>

Table 6-17 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

<table>
<tr><th colspan="9">FAIL SAFE ANALYSIS</th></tr>
<tr><th colspan="3">Loads Cases</th><th colspan="6">Fixed Bracket_Clamp Collar&Wedge
Materia:l 316L</th></tr>
<tr><th rowspan="2">Load Case</th><th colspan="2" rowspan="2">Case Description</th><th colspan="2">Max Stress [N/mm2]</th><th>Displacement</th><th colspan="2">Margin of Safety</th></tr>
<tr><th>Von Mises</th><th>Max Principal</th><th>(mm)</th><th>Yield</th><th>Ultimate</th></tr>
<tr><td>1</td><td colspan="2">HP TS switched</td><td>91.4</td><td>90.5</td><td>0.0701</td><td>1.63</td><td>5.08</td></tr>
<tr><td>2</td><td colspan="2">Peltier TS switched</td><td>96.3</td><td>97.1</td><td>0.1061</td><td>1.49</td><td>4.66</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Combined 1 and 2</td><td>HP Max</td><td>91.3</td><td>90.4</td><td>0.0748</td><td>1.63</td><td>5.08</td></tr>
<tr><td>Peltier Max</td><td>95.8</td><td>96.4</td><td>0.1051</td><td>1.51</td><td>4.71</td></tr>
</table>

Table 6-18 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

FAIL SAFE ANALYSIS							
Loads Cases			***Sliding Bracket*** ***Materia:l Al 7075***				
Load	Case		Max Stress *[N/mm2]*		Displacement	Margin of Safety	
Case	Description		*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	HP TS switched		55.4	40.6	0.0878	6.09	10.55
2	Peltier TS switched		84	59.2	0.0904	3.68	6.92
3	Combined 1 and 2	HP Max	58.5	43.3	0.0885	5.72	9.83
		Peltier Max	83.5	58.9	0.0897	3.71	6.96

Table 6-19 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

FAIL SAFE ANALYSIS							
Loads Cases			***Heat Pipe*** ***Material:316L***				
Load	Case		Max Stress *[N/mm2]*		Displacement	Margin of Safety	
Case	Description		*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	HP TS switched		70.3	41.8	0.091	2.41	12.16
2	Peltier TS switched		83.7	66.2	0.103	1.87	7.31
3	Combined 1 and 2	HP Max	75.2	47.1	0.092	2.19	10.68
		Peltier Max	67.2	63.6	0.109	2.57	7.65

Table 6-20 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

FAIL SAFE ANALYSIS							
Loads Cases			***Peltier Pipe Fixed*** ***Material:316L***				
Load	Case		Max Stress *[N/mm2]*		Displacement	Margin of Safety	
Case	Description		*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	HP TS switched		62.4	53.4	0.0312	2.85	9.30
2	Peltier TS switched		136	132	0.0718	0.76	3.17
3	Combined 1 and 2	HP Max	63.7	56.2	0.0339	2.77	8.79
		Peltier Max	135	131	0.0714	0.78	3.20

Table 6-21 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

FAIL SAFE ANALYSIS							
Loads Cases			***Peltier Heat Exchanger & Spring Support*** ***Material: 316L***				
Load	Case		Max Stress *[N/mm2]*		Displacement	Margin of Safety	
Case	Description		*Von Mises*	*Max Principal*	*(mm)*	Yield	Ultimate
1	HP TS switched		23.6	14.4	0.0955	9.17	37.19
2	Peltier TS switched		134	52.7	0.0465	0.79	9.44
3	Combined 1 and 2	HP Max	46.8	23.2	0.0182	4.13	22.71
		Peltier Max	132	52.1	0.0461	0.82	9.56

Table 6-22 Fail-Safe Analysis: Stress and Margin of Safety under different load cases

FAIL SAFE ANALYSIS							
Loads Cases			TS &Peltier heat exchanger press Material: 316L				
Load	Case		Max Stress [N/mm2]		Displacement	Margin of Safety	
Case	Description		Von Mises	Max Principal	(mm)	Yield	Ultimate
1	HP TS switched		114	123	0.0504	1.11	3.47
2	Peltier TS switched		194	151	0.0677	0.24	2.64
3	Combined 1 and 2	HP Max	118	127	0.0516	1.03	3.33
		Peltier Max	184	150	0.0674	0.30	2.67

Table 6-23 Fail-Safe Accu.Bracket Clamp&Collar Bolt Element Force and MoS (Preload: 65%)

Accu.Bracket Clamp&Collar Bolt element force and MofSafety Calculation（Fail Safe）									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
P+T_HP	-18.2	-10.7	-2.98	18.4	4.11	10.7	2.39	1.4	0.44
P+T_Peltier	-33.4	-86.2	-10.8	35.1	7.83	86.2	19.2	5.0	0.3

P+T_Combined_HP_Max	-18.9	-14.5	-5.64	19.7	4.40	14.5	3.24	1.6	0.43
P+T_Combined_Peltier Max	-33.3	-85.7	-10.6	34.9	7.79	85.7	19.1	5.0	0.3

Table 6-24 Fail-Safe PipeFix&Clamp Bolt Element Force and MoS Calculation

(Preload: 65%)

PipeFix&Clamp Bolt element force and MofSafety Calculation（Fail Safe）									
Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
P+T_HP	28	-24.4	11.1	30.1	6.72	24.4	5.45	0	0.5
P+T_Peltier	55.6	-80	25.3	61	13.62	80	17.86	0	0.49
P+T_Combined_HP_Max	30.5	-36.5	13.2	33.2	7.41	36.5	8.15	0	0.5
P+T_Combined_Peltier Max	55.3	-79.5	25.2	60.7	13.55	79.5	17.75	0	0.49

Table 6-25 Fail-Safe Press&Saddle Bolt Contraint Force and MoS Calculation

(Preload: 65%)

Press&Saddle* Bolt Contraint *force and MofSafety Calculation（Fail Safe）

Load Case	x	y	z	shear	Shear	Tension	Tension	Bending force	MofS
	(N)	(N)	(N)	(N)	(lbf)	(N)	(lbf)	(in.lbf.)	
P+T_HP	45.1	-172	49.4	177	39.51	49.4	11.03	0	0.20
P+T_Peltier	237	-742	59.3	779	173.88	59.3	13.24	0	0.20
P+T_Combined_HP_Max	76.3	-261	48.5	272	60.71	49.5	11.05	0	0.20
P+T_Combined_Peltier Max	234	-736	60	772	172.32	60	13.39	0	0.20

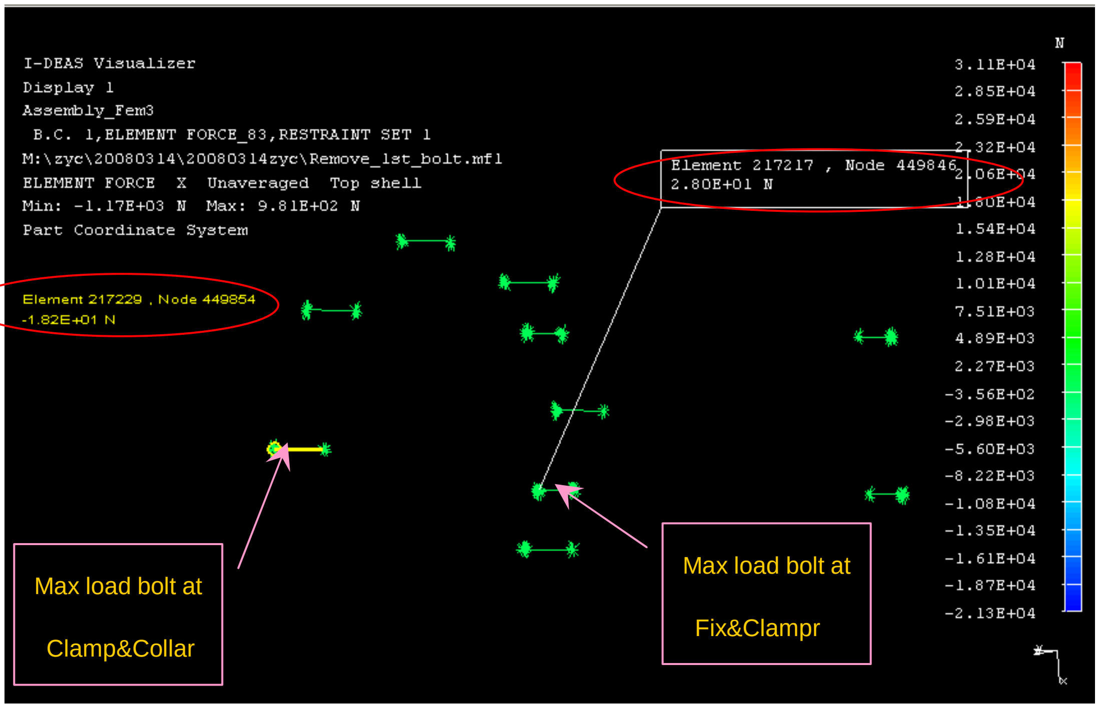


Figure 6-38 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element X-Directiion forces;

Load case: P+T_HP

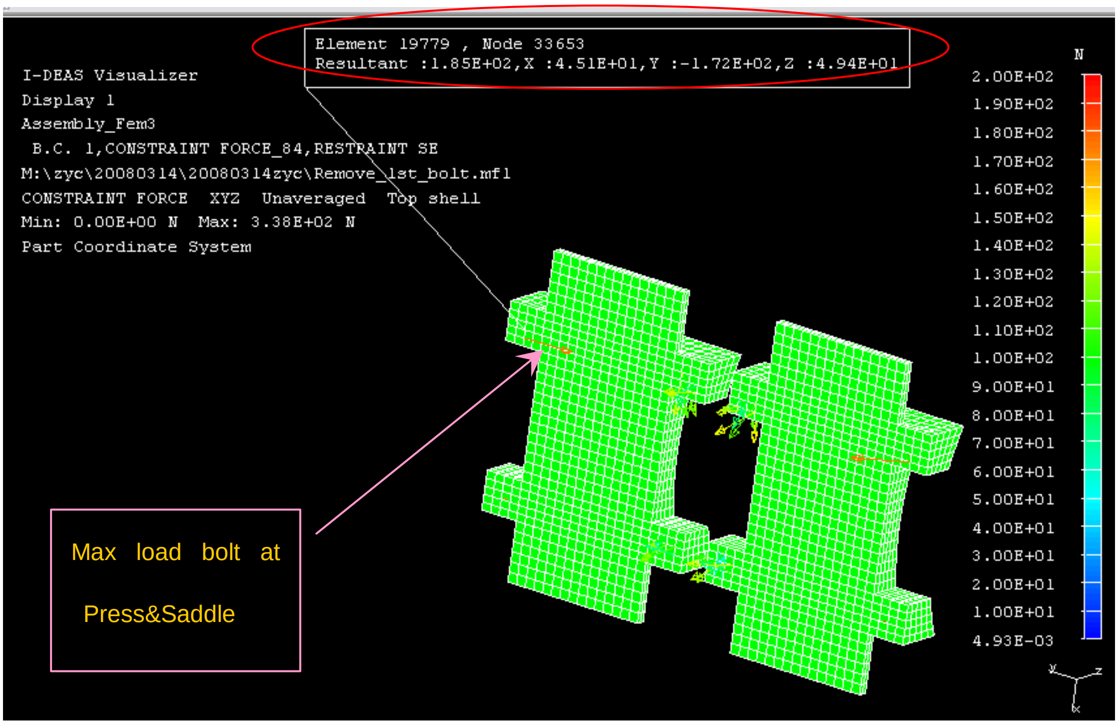


Figure 6-39 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case： P+T_HP

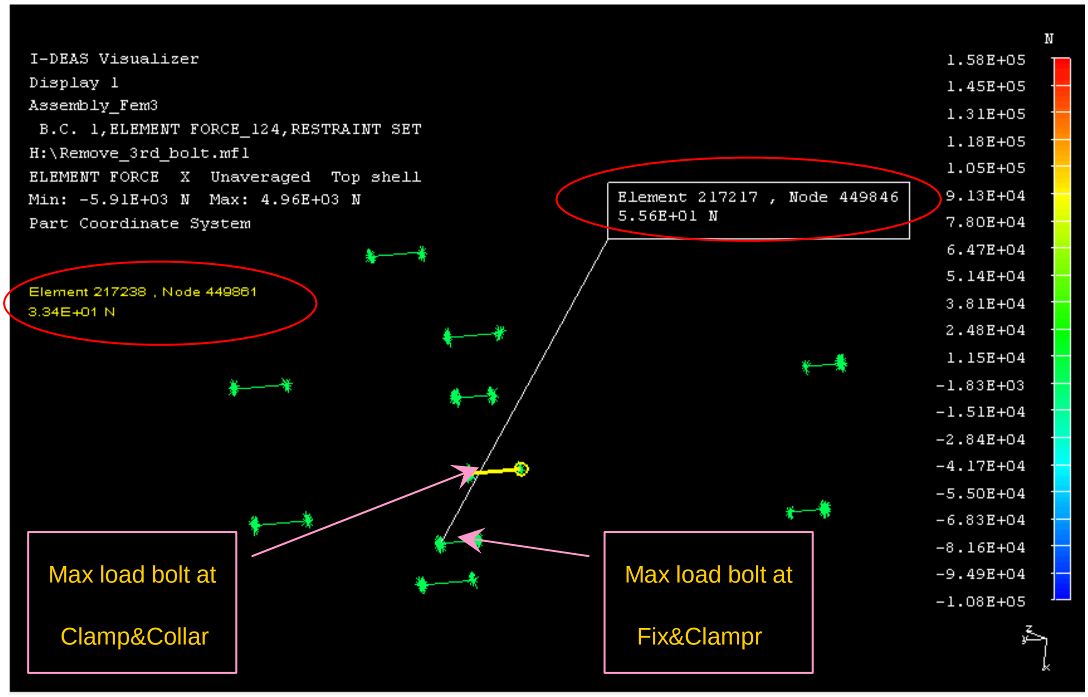


Figure 6-40 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element X-Drection forces;

Load case P+T_Peltier

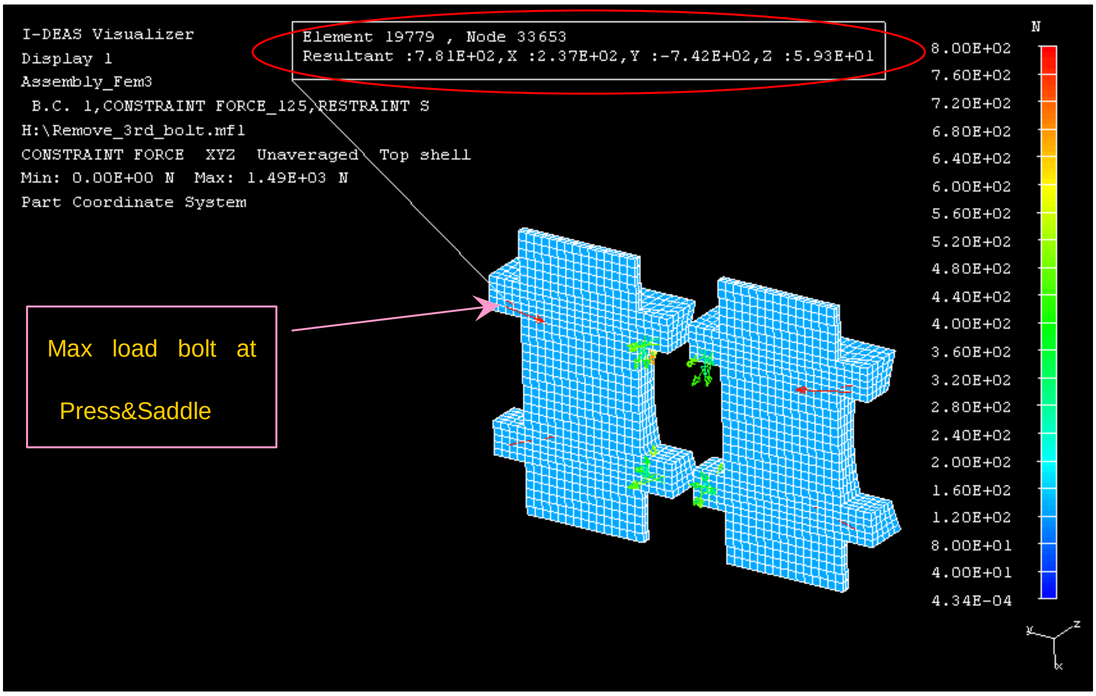


Figure 6-41 Fail-Safe Analysis:Peltier Saddle forces at Bolts location(P+T_Peltier)

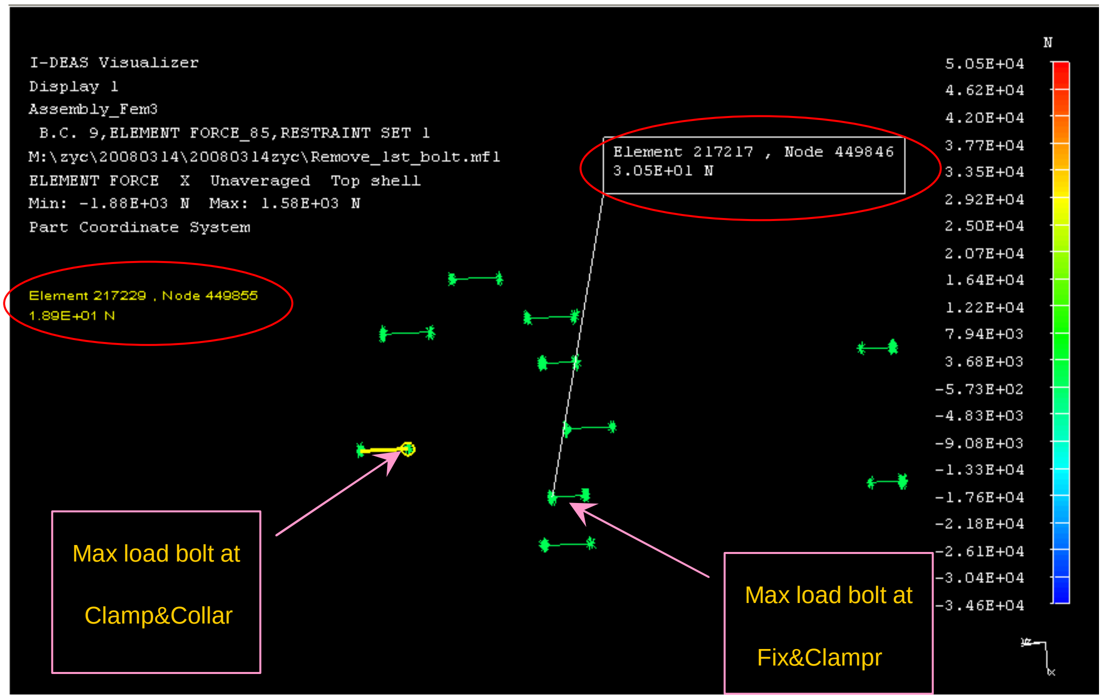


Figure 6-42 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element X-Drection forces;

Load case: P+T_Combined_HP_Max1

Figure 6-43 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case：P+T_Combined_HP_Max1

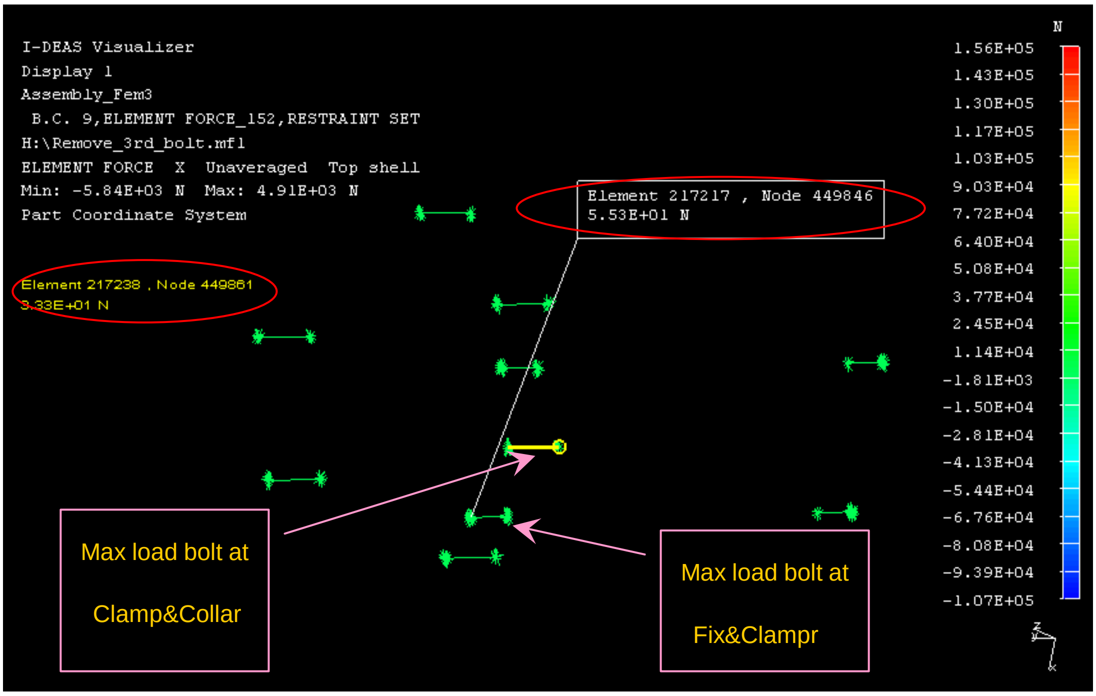


Figure 6-44 Fail-Safe Analysis: Clamp&Collar/ Fix&Clamp element X-Direction forces;

Load case P+T_Combined_Peltier Max

Figure 6-45 Fail-Safe Analysis:Peltier Saddle constraint forces at Bolts location

Load case：P+T_Combined_Peltier Max

7. MODAL ANALYSIS

For the Modal Analysis, the additive Mass in ACCU(CO2) and AHP(NH4) are removed. And a normal mode dynamics Lanczos Method was applied.

First mode is predicted at the natural frequency of 399.8 Hz. The first ten modes natural frequencies are listed in Table 7-1 and showed in Figure 7-1 to Figure 7-10

Table 7-1 the First Ten Modes Natural Frequencies

Mode	1	2	3	4	5	6	7	8	9	10
Frequency (Hz)	399.8	401.5	550.8	611.9	745.8	824.1	944.0	971.4	977.9	1080

First mode natural frequency satisfies structural requirements (1st mode> 50Hz)

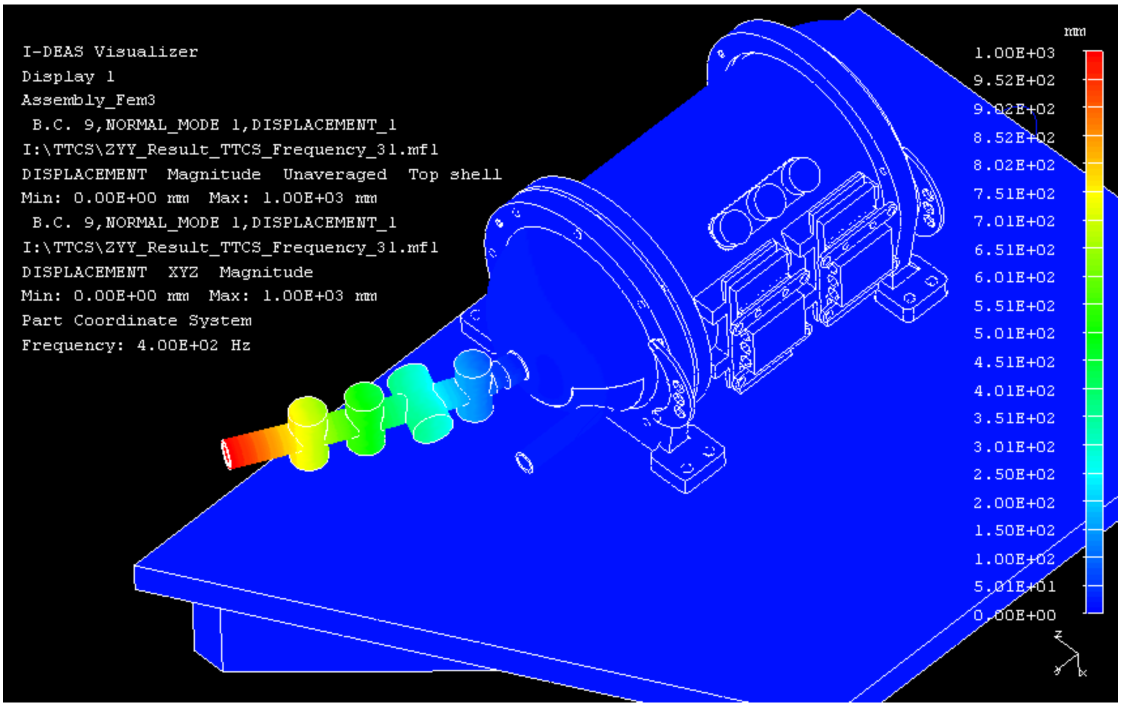


Figure 7-1 First Mode 399.8Hz

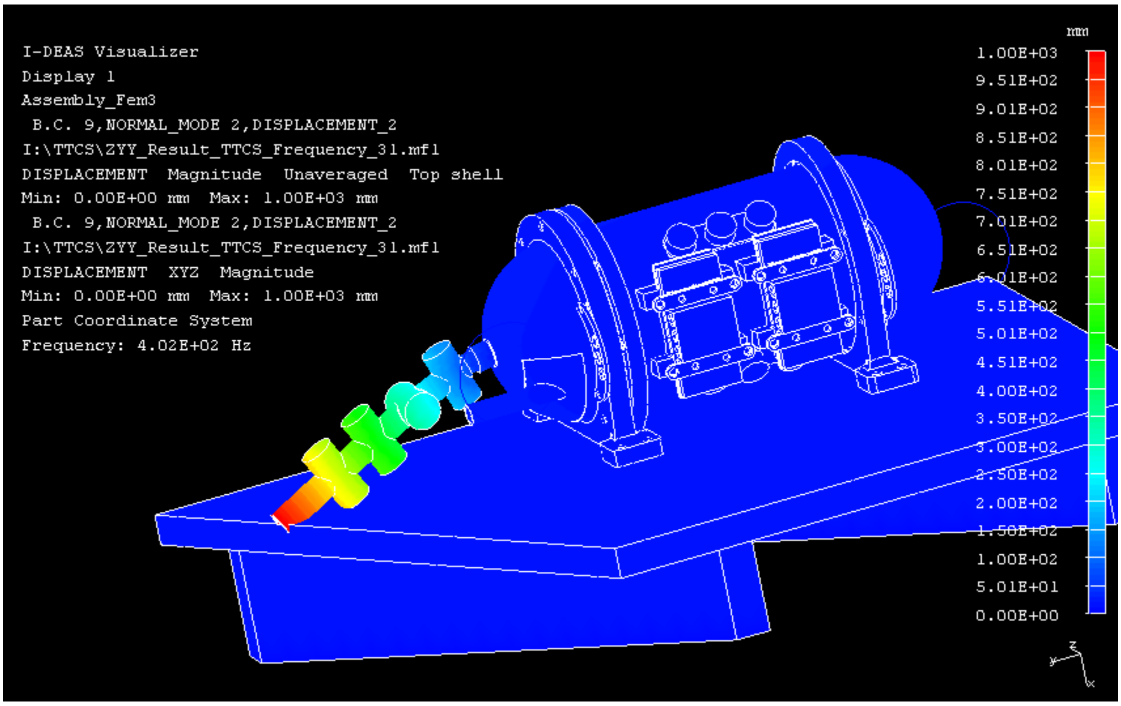


Figure 7-2 Second Mode 401.5Hz

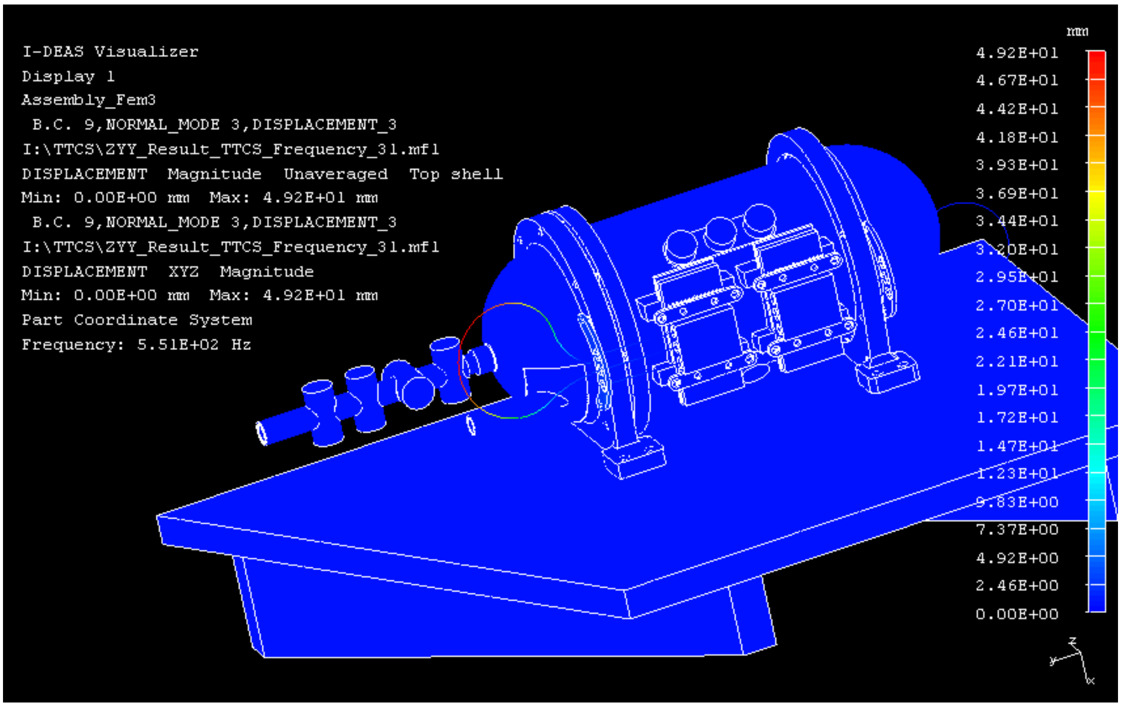


Figure 7-3 Third Mode 550.8Hz

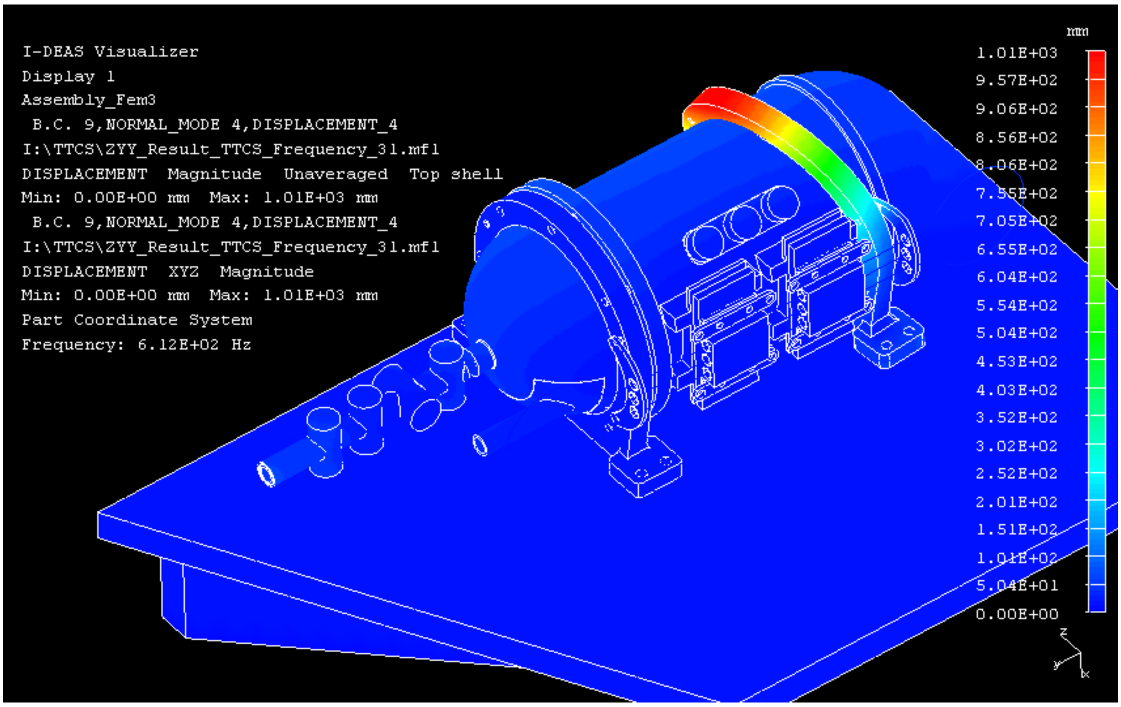


Figure 7-4 Fourth Mode 611.9Hz

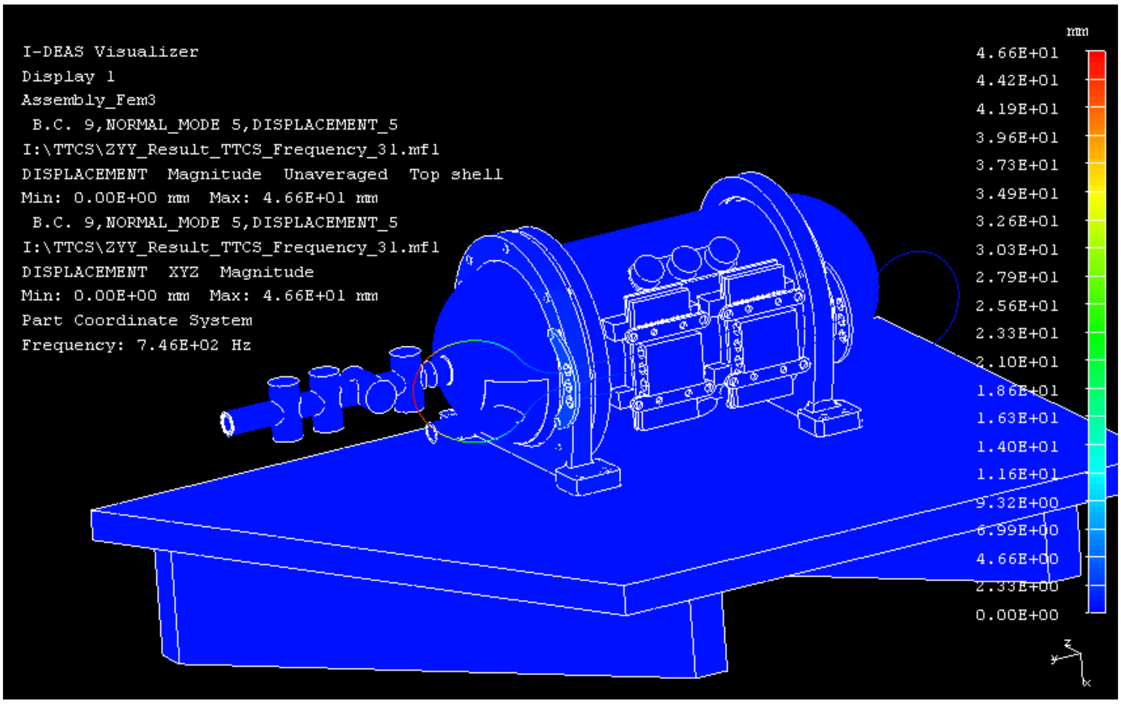
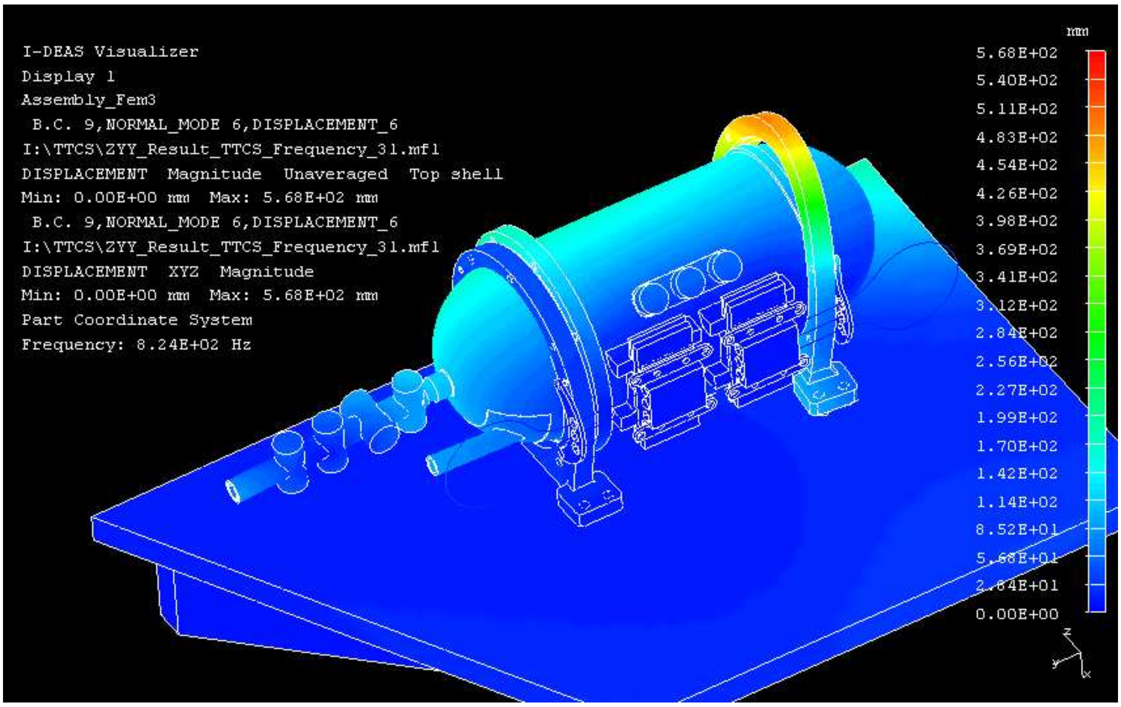


Figure 7-5 Fifth Mode 745.8Hz



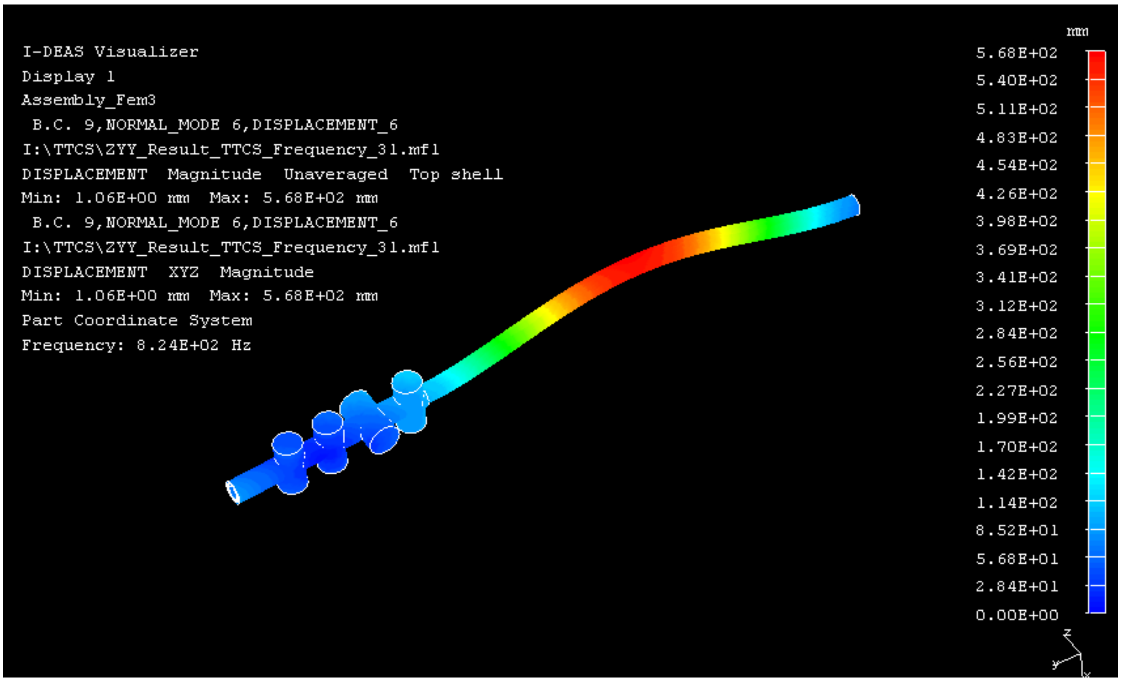
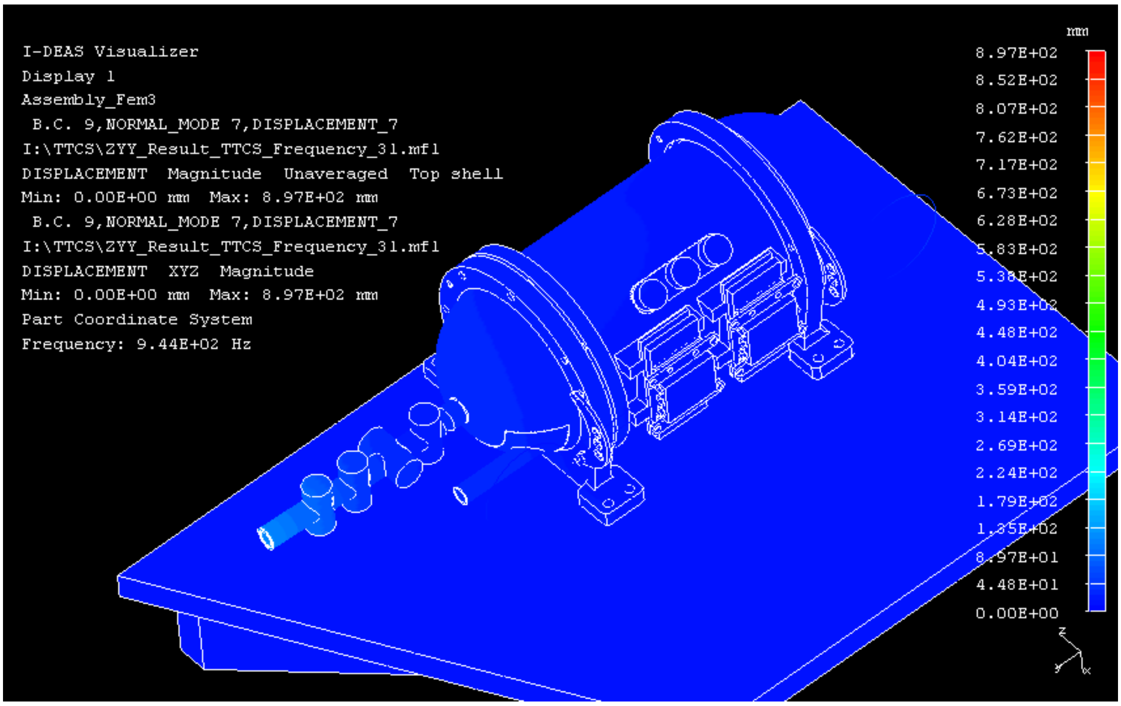


Figure 7-6 Sixth Mode 824.1Hz



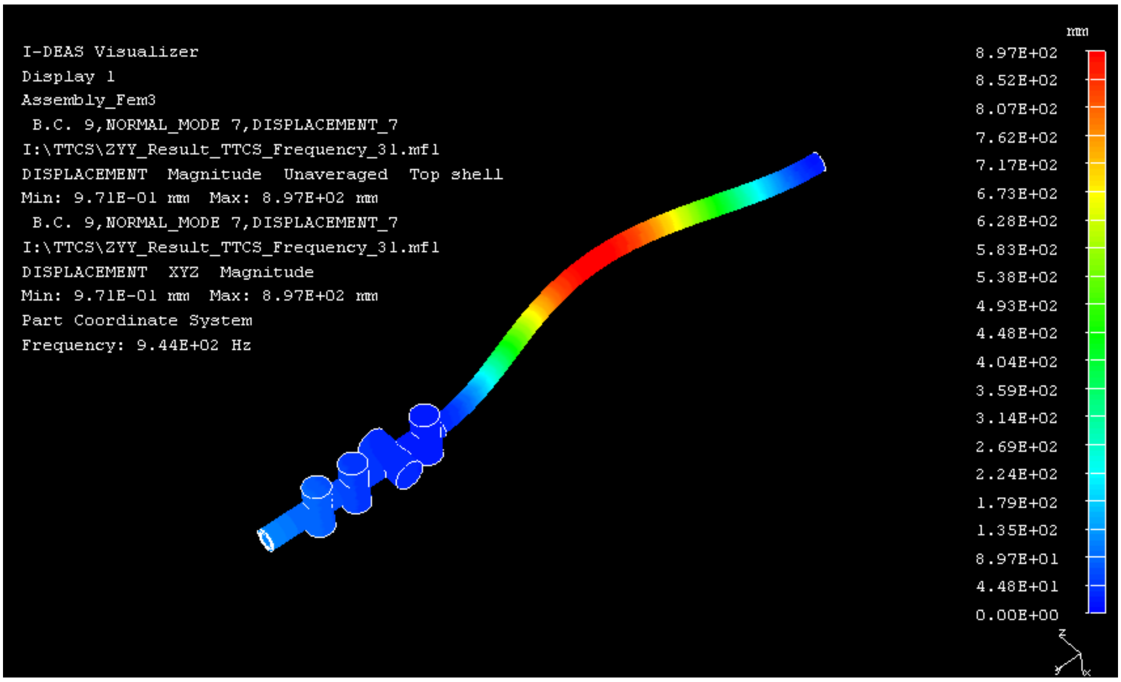


Figure 7-7 Seventh Mode 944.0Hz

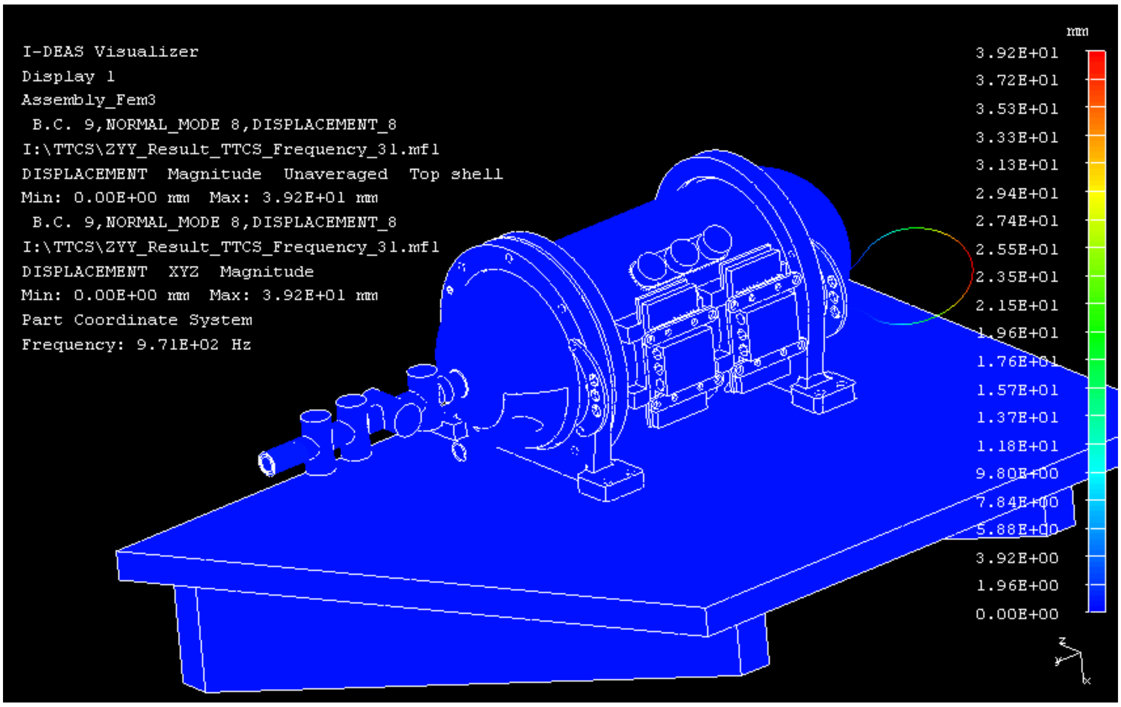
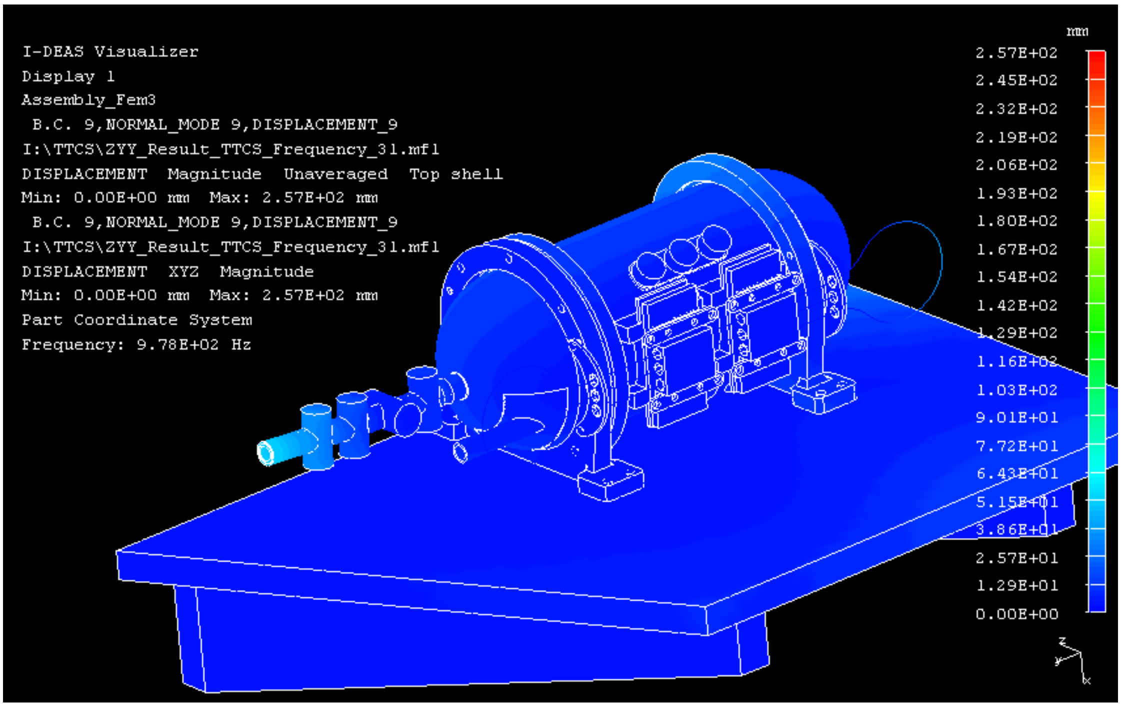


Figure 7-8 Eighth Mode 971.4Hz



I-DEAS Visualizer
Display 1
Assembly_Fem3
B.C. 9,NORMAL_MODE 9,DISPLACEMENT_9
I:\TTCS\ZYY_Result_TTCS_Frequency_31.mf1
DISPLACEMENT Magnitude Unaveraged Top shell
Min: 0.00E+00 mm Max: 2.57E+02 mm
B.C. 9,NORMAL_MODE 9,DISPLACEMENT_9
I:\TTCS\ZYY_Result_TTCS_Frequency_31.mf1
DISPLACEMENT XYZ Magnitude
Min: 0.00E+00 mm Max: 2.57E+02 mm
Part Coordinate System
Frequency: 9.78E+02 Hz
mm
2.57E+02
2.45E+02
2.32E+02
2.19E+02
2.06E+02
1.93E+02
1.80E+02
1.67E+02
1.54E+02
1.42E+02
1.29E+02
1.16E+02
1.03E+02
9.01E+01
7.72E+01
6.43E+01
5.15E+01
3.86E+01
2.57E+01
1.29E+01
0.00E+00

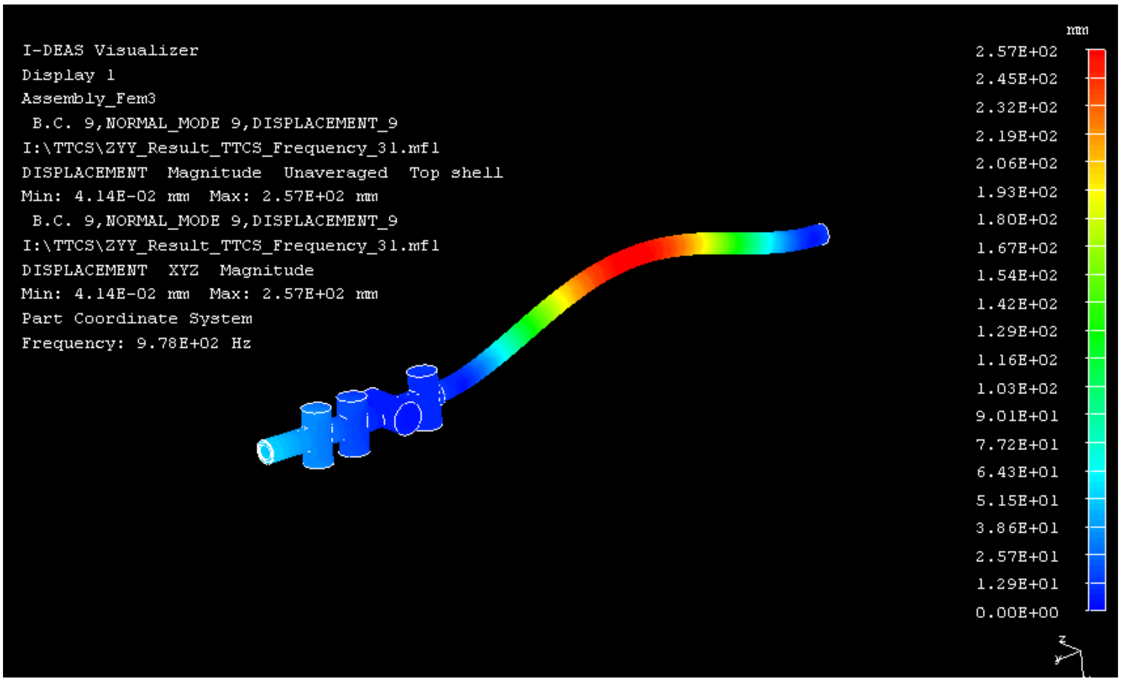


Figure 7-9 Ninth Mode 977.9Hz

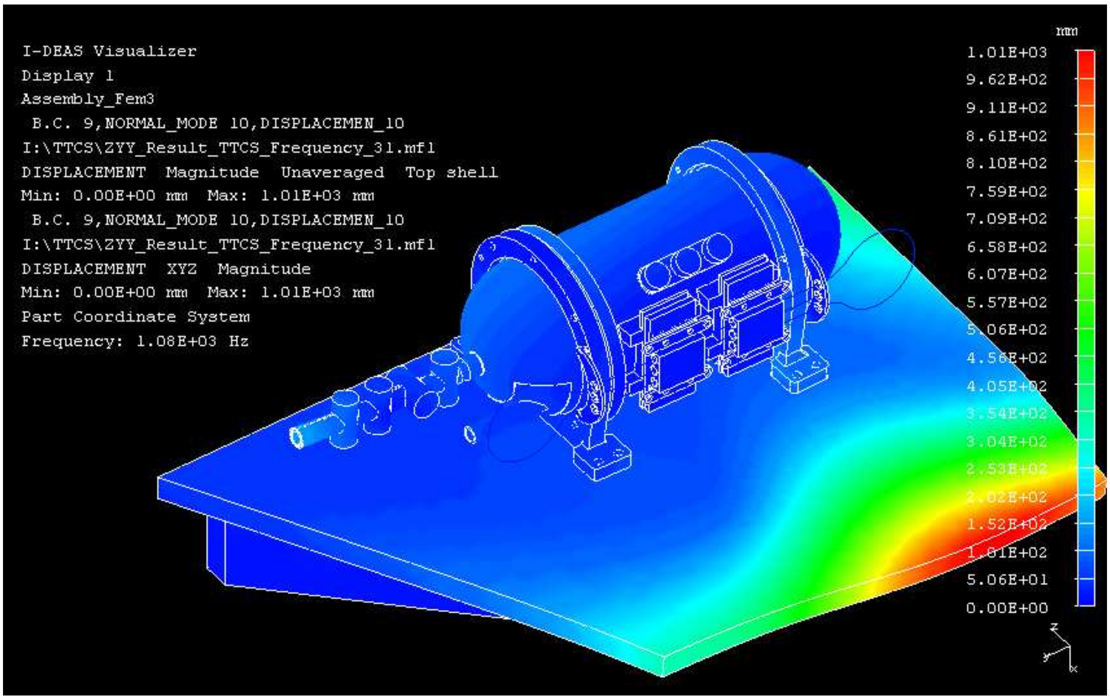


Figure 7-10 Tenth Mode 1080Hz

8. MINIMUM MOFS SUMMARY OF ALL LOADCASE

The minimum margins of safety of all component and bolt connections under all above load cases are summarized in table 8-1. Corresponding minimum Margin of Safety of fail-safe analysis are listed in table 8-2. Table 8-3 is the first ten natural frequency summery of the modal analysis. One thing need to be clarified for the report. During calculation, we find accumulator is the key part that has very low margin of safety. The weakest points happened on the welding or soldering locations. This may be caused by calculation because we didn't simulate soldering material in our model. Because accumulator is the most important subassembly in the TTCB, the test is performed to make sure a safe structure. Test result shows the accumulator is safe(see related test report). Other than the accumulator with the low margin of safety in the following tables, all other components and bolt connections show good margin of safety. In modal analysis, the first natural frequence is 399.8HZ, much bigger than the required 50HZ.

Table 8-1 Min. mofs summary of all the load cases

summary of the min. margins of safety(static and thermal)					
		Static:mofs		Thermal :mofs	
	Name	Yield	Ultimate	Yield	Ultimate
components	Accumulator	0.03	0.11	0.02	0.02
	Fixed Bracket & Clamp Collar&Wedge	1.1	2.11	1	1.82
	Sliding Bracket	4.01	3.56	2.76	2.95
	Heat Pipe	1.05	2.46	0.92	1.14
	Peltier Fixed	2.07	2.26	0.51	1.2
	TS & Peltier Heat Exchanger &Peltier heat exchanger press &Spring Support	0.61	1.13	0.68	1.22
		Static :bolt mofs		Thermal: bolt mofs	
connection	Accu.Bracket Clamp&Collar Bolt	0.12		0.09	
	PipeFix&Clamp Bolt	0.123		0.122	
	Press&Saddle Bolt	0.107		0.106	

Table 8-2 summary of the min. mofs of all the load cases(Fail safe)

summary of the min. margins of safety (Fail-safe)					
	Name	static :mofs		Thermal: mofs	
		Yield	Ultimate	Yield	Ultimate
	Accumulator	0.54	1.8	0.53	1.55
	Fixed Bracket & Clamp Collar&Wedge	1.61	5.17	1.49	4.66
	Sliding Bracket	6.91	8.85	3.68	6.92
	Heat Pipe	1.07	9.19	1.87	7.31
	Peltier Fixed	4.94	16.41	0.76	3.17
parts	TS & Peltier Heat Exchanger &Peltier heat exchanger press& Spring Support	0.98	3.2	0.24	2.64
		static: bolt mofs		Thermal:bolt mofs	
	Accu.Bracket Clamp&Collar Bolt	0.34		0.3	
	PipeFix&Clamp Bolt	0.5		0.49	
joints	Press&Saddle Bolt	0.19		0.2	

Table 8-3 the First Ten Modes Natural Frequencies

Mode	1	2	3	4	5	6	7	8	9	10
Frequency (Hz)	399.8	401.5	550.8	611.9	745.8	824.1	944.0	971.4	977.9	1080